STUDIES ON THE PREVALENCE OF ALGAL BLOOMS ALONG KERALA COAST, INDIA

Thesis submitted to
Cochin University of Science and Technology
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

UNDER THE FACULTY OF MARINE SCIENCES

BY

JUGNU. R
(Register No. 2469)

POST GRADUATE PROGRAMME IN MARICULTURE
CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

JANUARY 2006

Dedicated to

my family

CERTIFICATE

This is to certify that this thesis entitled **'Studies on the prevalence of algal blooms along Kerala coast, India'** is an authentic record of research work carried out by Jugnu R (Reg. No.2469), under my guidance and supervision in Central Marine Fisheries Research Institute, Cochin, in partial fulfillment of the requirements for the Ph D degree in MARINE ECOLOGY of Cochin University of Science and Technology and no part of this has previously formed the basis for the award of any other degree in any university.

Kripa. V

Dr. V. KRIPA
(Supervising guide)
Senior Scientist,
CMFRI, Cochin.

Date : 3-1-06.

CONTENTS

PREFACE

Algal blooms are naturally occurring phenomena in the aquatic environment. Algae, which are the primary producers of this environment, act as important channels for transferring carbon and energy into the food web. Thus, seasonal algal blooms are important from an ecological point of view. But there are exceptional blooms caused by noxious or toxic microalgal species. These blooms cause mass mortalities of wild and farmed fish and shellfish, human intoxications which sometimes result in death, alteration of marine trophic structure through adverse effects on larvae and other life history stages of commercially important species and death of marine animals.

Though exceptional algal blooms have occurred throughout the recorded history, the public health and economic impacts of these phenomena have been especially severe, and is on the rise during the last few decades. They form a serious constraint to the development of coastal areas, which calls for a coordinated scientific and management approach.

Occurrences of harmful algal blooms and associated mortality have been reported along the coastal waters of India since the early period of the last century. The distribution, extent and harmful effects of these blooms have been increasing during the past few years. This can be a serious problem, since increasing areas of our coastal waters are at present being brought under aquaculture. With the development of a global perspective for products cultured in healthier waters, the recurrence of harmful algal blooms can reduce the demand for our products. This will lead to a serious setback to coastal mariculture activities along the coast, especially bivalve mariculture activities, which are still in the developmental stages. Keeping this in view, the present study was taken up to study the dynamics of major phytoplankton blooms which occur along the Kerala coast.

The present study is entitled **'Studies on the prevalence of algal blooms along Kerala coast, India'.**

A general introduction to the theme of the topic namely 'Algal blooms' and the work is given in the beginning. The results of qualitative and quantitative analysis of phytoplankton in the coastal waters of Vizhinjam and Chombala, their species diversity and community structure is presented in the first chapter. The results of the analysis of the major hydrographic and meteorological parameters at these sites is included.

In the second chapter, the major algal blooms recorded along the coast of Kerala during the study period is described and their occurrence is related to the hydrographic and meteorological variations.

In the third chapter, changes in fishery landings at Calicut, with the blooming of harmful algae in this region during the study period is described.

A brief introduction and a review of the major works in the relevant area is given at the beginning of each chapter. In the concluding session, the summary of the work and the references cited in each chapter is given.

several species of *Dinophysis* like *D.acuminata, D.acuta, D.fortii. D.norvegica, D.rotunda, D.tripos* and suspected in *D.caudata, D.hasta and D.sacculus* (Lee *et al.*, 1989).

ASP was reported for the first time in 1987 in Prince Edward Island Canada, where cultured blue mussel was implicated in 127 cases of poisoning and two deaths. *Pseudo-nitsczhia multiseries* was identified as the harmful microalga (Bates *et al.*, 1989). A recent study by Bates *et al.* (1998) points out that *Pseudo-nitsczhia* spp is more cosmopolitan in occurrence than previously thought, with reported occurrence from Canada, North America, Holland, Denmark, Spain and New Zealand. CFP results from a consumption of reef fishes contaminated with algal toxins and humans consuming such fishes suffer from gastrointestinal and neurological illness and in extreme cases can die from respiratory failure. The benthic dinoflagellate *Gambierdiscus toxicus, Osteropsis siamensis, Coolia monotis and Prorocentrum lima* are thought to be the causative organisms. From being a rare occurrence two centuries ago, Ciguatera has now reached epidemic proportions in French Polynesia, with more than more than 24,000 patients of CFP reported from the area between 1966 and 1989 (Hallegraeff, 1995). Neurotoxic shellfish poisoning (NSP) caused by the dinoflagellate *Gymnodinium breve*, which was earlier thought to be endemic to the Gulf of Mexico region, has been now reported from other regions of the world like New Zealand (Richardson, 1997). All these point to a global spread of harmful algal bloom forming species.

Algal toxins can also alter the marine ecosystem, structure and function as they are passed through the food web affecting fecundity and survival at different trophic levels. Some of the microalgae kill wild and farmed fish populations. Fish mortalities are due primarily to *Gymnodinium nagasakiense* in the North Sea region, *Heterosigma akashiwo* in British Columbia, Chile and New Zealand and due to *Chattonella antiqua* in Japan. Besides direct fish kills caused by toxins produced by these algae, indirect kills can also occur as caused by the spine like process present on the setae of the diatoms *Chaetoceros convolutus* and *Chaetoceros concavicornis*. Some other harmful microalgae like *Gymnodinium breve* produce toxic and irritating aerosols. Other recent additions to the list are the silicoflagellate *Dictyocha speculum* and the prymnesiophyte *Chrysochromulina polylepis* which have been recorded as the causative species in many recent marine faunal kills (International Oceanographic Commission workshop, 1991).

Along the Indian coast, algal blooms and associated mortality have been recorded since the early half of the 20th century by many workers (Hornell, 1917; Aiyar, 1936; Jacob and

Menon, 1948; Bhimachar and George, 1950; Subrahmanyan, 1954). They have been reported to be more prevalent along the west coast than on the east coast. Algal blooms particularly HAB occurrences along the Indian coast have been reviewed by Karunasagar and Karunasagar (1990), including the major reasons for these blooms and the harmful effects they have caused. The harmful algae with regular bloom occurrence along the Indian coast are *Noctiluca scintillans* and *Trichodesmium* sp. *Chattonella marina* is a regular bloom forming species along the Calicut coast. Sporadic blooms of other harmful microalgae like dinoflagellate *Gonyaulax polygramma* along south west coast has been reported by Prakash and Sharma (1964) and along the coastal waters off Cochin by Gopinathan and Pillai (1976). Bloom of *Gymnodinium mikimotoi* along Kanara coast has been reported by (Karunasagar and Karunasagar, 1992; 1993). Planktonic and cyst forms of *Gymnodinium catenatum* have been reported along the coastal waters of Karnataka by Godhe *et al.* (1996).

Shellfish poisoning from algal toxins have also caused human fatalities and related discomforts along the Indian coast. In 1981, an incident of paralytic shellfish poisoning resulted in the hospitalization of 85 people and death of 3 persons due to consumption of the bloom affected clam *Mereterix casta* in Tamil Nadu. A similar incidence took place in Mulki estuary, Mangalore, in 1983 (Karunasagar, 1984; Bhat, 1981; Devassy and Bhat, 1991). In both the cases the toxic species could not be identified. Similarly at Poovar, near Vizhinjam in Kerala, 5 children died and more than 300 people were hospitalized in October 1998, due to shellfish poisoning from *Gonyaulax polygramma* (Karunasagar *et al.*, 1997). Recently, on 17 th September 2004, a massive fish kill was noticed along the Trivandrum coast, along with foul smell coming from the sea. Many people, especially children, residing in the coastal districts of Trivandrum and Kollam, who got exposed to the stench, were hospitalized due to vomiting and nausea (The New Indian Express, 17 th September, 2004). It was later identified to be caused by a bloom of the toxic dinoflagellates *Gonyaulax diegensis* and *Cochlodinium* spp (CMFRI Newsletter, 2004).

Due to its global distribution, the problem of HAB can be addressed comprehensively and effectively only through international, interdisciplinary and comparative research. Global monitoring programmes are designed and implemented to manage this problem more effectively. The first attempt for this was the creation of a 'Harmful Algal Programme' by IOC (International Oceanographic Commission) and UNESCO in 1989 followed by the formulation of ECOHAB (Ecology and Oceanography of Harmful Algal Blooms) programme by USA. The second international initiative was the GEOHAB programme (Global Ecology and Oceanography of Harmful Algal Bloom), by IOC and SCOR (Scientific committee on Ocean Research). The

European union also sponsors an European initiative on HAB's known as EuroHAB. Other international organisations like PICES (North Pacific Marine Organisation), APEC (Asian Pacific Economic Cooperation) have all set up programmes and workshops on HAB's. Besides, many of the coastal nations have local monitoring programmes, which have resulted in increased sampling intensity and frequency for identifying the presence of harmful microalgae. Workshops and conferences are being held every year to identify the most pressing research issues in the field.

Along the Indian coast, exceptional algal blooms can lead to serious constraints for the sustainable development of coastal areas, which calls for a coordinated scientific and management approach. Marine resource utilisation through fishing and mariculture activities has witnessed a phenomenal increase along the coast during the past few decades. The coastal mariculture programmes of the marine mussel *Perna viridis* (Linnaeus, 1758) and the edible oyster *Crassostrea madrasensis* (Preston), involving more than 8000 coastal rural families in Kerala, producing more than 4500 tones of farmed bivalve per annum is a direct indication in the phenomenal increase in coastal resource utilisation. Under these circumstances, the potential danger lurking behind the bivalve farmers and the consumers, through unpredicted harmful algal blooms has to be prioritized and precautionary steps taken to avoid human causalities and large scale economic losses.

Early warnings when harmful species or toxins reach critical concentration is the most widely used management strategy, which helps in implementing specific plans to avoid health problems and to minimise the economic losses. At a long time scale, it is essential to assess the risk of harmful events while planning the utilisation of coastal areas and for this, basic knowledge and a firm database about the species distribution, species succession and population dynamics of the bloom forming species is required. Hydrodynamic and ecologic conditions that lead to their blooming has to be studied which would help to build predictive models. Keeping this in view, the present research study entitled 'Studies on the prevalence of algal blooms along Kerala coast, India' has been under taken.

CHAPTER I

1. PHYTOPLANKTON DYNAMICS ALONG THE NORTH AND SOUTH COASTS OF KERALA

1.1. INTRODUCTION

The exceptional bloom forming species constitute only a mere 5.5-6.7% of the total phytoplankton flora of the world's oceans (Sournia, 1995). The mere presence of an exceptional bloom forming taxa does not mean that it will bloom. The bloom of a species is often triggered by factors separate from those favouring the survival of seed stock. Most of the studies on bloom events have focused and monitored the hydrographic and environmental parameters only after the visible development of the bloom and efforts have been made to relate it with the occurrence of the bloom. Valuable information on factors which trigger the bloom are thus lost, which are essential for the development of predictive models. Also, according to Richardson (1997), most studies on harmful algal blooms focus only on the bloom forming algae and not on other phytoplankton species of the community which coexist in the region. Species abundance data is considered crucial, as it gives valuable information on quantitative and qualitative changes in the relative frequency of occurrence of exceptional/ harmful algal species. A continuous study is thus essential for understanding the bloom dynamics of a region. Such long term studies on the phytodynamics was carried out in the Narragensett Bay by Karentz and Smayda (1984) and in North Sea by Reid *et al.* (1990). Distribution of *Dinophysis* sp and *Alexandrium* sp along French coasts since 1984 was studied by Belin (1993). Long term studies on the changes in physicochemical and biological factors in Victoria harbour, Port shelter and Tolo harbour in Hongkong, where there was a recent increase in intensity of algal blooms was done by Yung *et al.* (1997, 1999, 2001).

Being the primary producers of the aquatic environment, several studies have been conducted on the varied aspects of phytoplankton along the Indian coast since the very early part of the last century itself. One of the most important and comprehensive study on the phytoplankton of the west coast of India was by Subrahmanyan, the results of which were published in three parts. The first part (1959a) describes the quantitative and qualitative fluctuation of total phytoplankton and zooplankton crop and their relationship to fish landings. Physical and chemical factors influencing the distribution and abundance of phytoplankton was presented in Part 2 (1959b). Seasonal distribution along with relevant monthly observations on meteorological and hydrological conditions during the study period was presented in Part 3 (Subrahmanyan and Sharma, 1960). The marine diatoms of Trivandrum coast were identified by

Nair (1959). Extensive studies on phytoplankton have been done in the Cochin backwaters in the 70's (Gopinathan *et al.,* 1974; Devassy and Bhattathiri, 1974; Joseph and Pillai, 1975; Kumaran and Rao, 1975). Besides coastal waters, ecology of phytoplankton has also been studied in the estuarine and near shore waters of Mandovi and Zuari system in Goa (Rajgopal, 1981), in Vellar estuary (Joseph, 1982), in Dharmatar creek (Tiwari and Vijayalakshmi, 1998) and in Netravati estuary (Gowda *et al.*, 2001). The variation in physicochemical and biological variables in the eastern Arabian Sea from Cape Comorin to Kandla was described by Pillai *et al.* (2000).

Studies on primary productivity of the coastal waters have also been carried out extensively. The productivity of the Indian waters and the potential fishery resources they can support was estimated by Nair *et al.* (1968). A study on the biological productivity of the coastal waters, from Dabohl in the west, to Tuticorin in the east was done by Qasim (1978). The primary productivity and related physicochemical aspects in the near shore waters of Vizhinjam was studied by Rani and Vasantha (1984). The studies on primary productivity of Mandovi and Zuari estuarine system was done by Krishnakumari *et al.* (2000) and in Gurupur estuary of Mangalore coast by Gowda *et al.* (2002). The seasonal variation of phytoplankton and productivity in the surf zone and backwaters at Cochin was done by Selvaraj *et al.* (2003). This work compared the phytoplankton characteristics of the system to that in the 70's when extensive work on the phytoplankton and productivity was carried out by many workers in this region. The concentration of major pigments in the west coast of India and their relation to major nutrients during the post-monsoon of October to November 1999 was studied by Gopinathan *et al.* (2001). Distribution of chlorophyll pigments in the Arabian Sea off Mangalore in relation to nutrients was done by Lingadhal *et al.* (2003).

Similar studies have also been conducted along the east coast. The phytoplankton characteristics along the east coast has been studied very early by Ganapati and Rao (1953, 1958) and in the inshore waters of Mandapam by Prasad (1954, 1958) and Prasad and Nair (1960). Marichamy *et al.* (1985) studied the primary and secondary production in relation to hydrography in the inshore waters of Tuticorin for a period from 1983 to 1984. Primary production of the same region in relation to hydrographic parameters for the period from 1985 to 1987 was done by Gopinath and Rodrigo (1991). Phani and Raman (1992) studied the diversity and species assemblage patterns in the Northwest Bay of Bengal. A study on ecology of phytoplankton in Cuddalore and Uppanar estuary was done by Murugan and Ayyakkannu (1993) and species diversity in Hugli estuary by De *et al.* (1994). Qualitative and quantitative distribution of phytoplankton and its seasonal and regional variation in the coastal waters of the east coast was done by Geetha and Kondalarao (2004).

All these studies have focused on the distribution pattern of the phytoplankton community as a whole. The present study focuses more on the algal bloom forming species in the inshore waters. For this, general background information on the phytoplankton community of the region along with associated physical chemical and biological variables of the region is essential. A two year phytoplankton monitoring program along with associated hydrographic parameters was carried out so as to ascertain the regional and seasonal distribution of exceptional bloom forming species in our waters and to study their bloom dynamics. The chapter contains the results of this monitoring program carried out at the two stations, Vizhinjam and Chombala.

1.2. MATERIALS AND METHODS

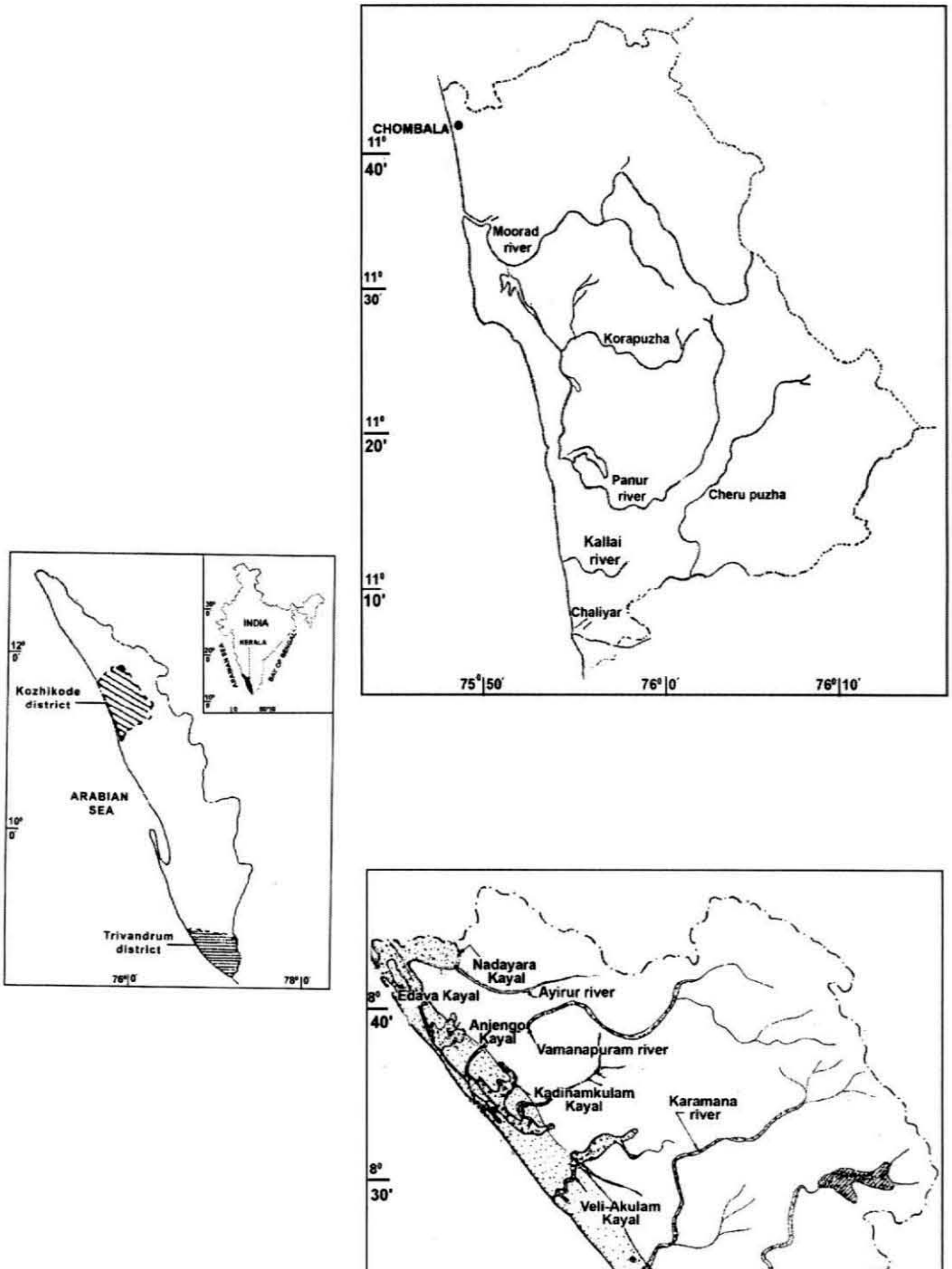
1.2.1. STUDY SITE

A continuous and regular phytoplankton monitoring was done at two sites, one each along the north and south coasts of Kerala. Sites were selected on the basis of previous records of harmful algal bloom occurrences. Vizhinjam in Trivandrum district, situated in the extreme southwest coast of India (Lat 8^0 22' N, Long 76^o 56' E) was selected as sampling station along south Kerala. A natural bay (Vizhinjam bay) is present in the region formed by two rock promontories, Mathalipuram on the west and Kottapuram in the east, which makes the area an enclosed water body facilitating fishing and mariculture operations. Samples were collected from two sites at Vizhinjam, one from within the bay and the other from the adjacent sea. Chombala in Calicut district (Lat 11^0 43' N, Long 75^o 33' E) was selected as the sampling site in the north coast of Kerala. The sampling stations are shown in Fig.1.1. Samples were collected from a depth of 8 meters at a distance of about 3 kilometers from the shore, at Chombala and Vizhinjam sea. In the bay, the depth was 6 meters.

1.2.2. FIELD SAMPLING

Sampling was done at a monthly frequency at both these stations for a period of two years, Chombala from October 2001 to September 2003 and at Vizhinjam from October 2001 to August 2003. Sampling could not be done during September 2003 at Vizhinjam, as the sea was very rough due to northeast monsoon winds.

Fig.1.1. Location of the two continuous sampling sites- Vizhinjam and Chombala



The physicochemical parameters such as temperature, salinity, pH, total suspended solids and biochemical oxygen demand were measured at the sampling site itself. Samples for the estimation of primary productivity and dissolved oxygen were fixed at the site and later analysed in the lab. Water samples were collected in 1 liter cans and transported immediately to the lab for the estimation of chlorophyll and major nutrients. Phytoplankton sample for both qualitative and quantitative analysis was collected from Chombala, Vizhinjam sea and bay region, fixed with 4% formaldehyde and brought to the lab for further analysis. Samples were collected in duplicates for all the parameters and analysis.

Temperature was measured using a hand-held centigrade thermometer, graduated from 0 to 50° C and with a precision of 0.1° C. Salinity was measured using a hand held refractometer by [ATAGO-Smill-E (Japan)] and was expressed in ppt. pH was measured using a digital pH meter (LABINDA pH analyser) having glass calomel electrode and calibrated with standard buffers. Total suspended solids and biochemical oxygen demand of the water samples were measured using a field pastel UV spectrophotometer.

1.2.3. LAB ANALYSIS

A. PHYSICOCHEMICAL PARAMETERS

i). Dissolved oxygen: Dissolved oxygen of the samples was estimated based on Winkler's method (1888).

ii). Nutrients: Concentration of the major nutrients ammonia, phosphate, nitrate and nitrite was analysed as per standard procedures in the lab. Periodic calibrations were carried out with reference standards and also for each set of reagents. Ammonia was estimated using the phenol-hypochlorite method (Zolarzano, 1969) and phosphate by the ascorbic acid method by Murphy and Riley (1962). Nitrite was first reduced to nitrate by the Cadmium- copper column reduction method and the nitrate then estimated by sulphanilamide method by Morris and Riley (1963) with modifications suggested by Grasshoff (1964) and Wood *et al.* (1967).

B. BIOLOGICAL PARAMETERS

i). Chlorophyll: Chlorophyll concentration which is a measure of the biomass of the region was estimated based on the method described by Parsons *et al.* (1984).

ii). Primary productivity: Surface primary productivity at the sampling sites was estimated using the dark and light bottle method (Gaarder and Gran, 1927).

iii). Phytoplankton analysis: Phytoplankton samples for qualitative and quantitative analyses were collected from the stations. Qualitative analysis was done for a period of two years at all the stations while quantitative analysis was for a period of one year, from September 2002 to September 2003 at Chombala and from August 2002 to August 2003 at Vizhinjam.

For qualitative analysis, phytoplankton was collected using a phytoplankton net of mesh size 30 μ, mouth diameter 50 cm and with a total length of 1 meter. The net was hauled horizontally for 15 minutes from a boat. After hauling, the phytoplankton sample collected in the bucket at the end of the net was poured into a plastic container after rinsing the net with seawater. The sample was immediately preserved with 4% formaldehyde for further analysis in the lab. From the qualitative analysis, percentage composition of the phytoplankton species was calculated. For quantitative analysis, 1 liter of water sample was collected, fixed with 4% formalin and brought to the lab for enumeration. Quantitative estimation of phytoplankton was done by sedimentation method (Utermohl, 1958). One ml of the phytoplankton in the sedimented sample was counted using a Sedgewick rafter cell counter. Enumeration was done in triplicates and the average count of phytoplankton expressed in cells l^{-1}.

The phytoplankton was observed under an inverted microscope (Leica) and identified upto species level wherever possible. The identification of species into different taxonomic categories was based on the keys described by Subramanyan (1946, 1968, 1971), IOC manual (1995) and Tomas (1996).

1.2.4. METEOROLOGICAL PARAMETERS

The data on rainfall and humidity was collected from daily weather report data (October 2001 to September 2003) published by the meteorological center at Trivandrum

1.2.5. STATISTICAL ANALYSIS

A. DIVERSITY INDICES

Diversity indices were calculated using PRIMER v5 software (Clarke and Warwick, 1994).

i). Margalef's species richness: Margalef's species richness is a measure of the number of species present, making some allowance for the number of individuals belonging to each species. It was calculated according to the formula,

$$\text{Species richness (Margalef): } d = (S\text{-}1)/\log_e(N),$$

where, S =No. of species, N=No. of individuals

ii). Shannon- Wiener's diversity index: Shannon-Wiener's diversity was calculated for measuring the variation in phytoplankton species diversity of the region over the two year period. This was calculated according to the formula

$$H' = \sum^{s}_{i} Pi \; \log_e(Pi)$$

where *s*, is the number of species, and P*i* is the proportion of the total number of individuals consisting of the *i*th species.

iii). Pielou's evenness: Pileou's evenness, a measure of equitability indicating how evenly the individuals are distributed among the different species, was calculated according to the formula

$$J' = H'/\log_e(S),$$

where H' = Shannon-Wiener's diversity index, S=No.of species

B. CLUSTER ANALYSIS

Cluster analysis was done to find months with similar species composition and to detect if there was any seasonality in occurrence of the dominant phytoplankters at the site. SIMPER analysis (analysis of similarity percentages) was then performed to identify the species which contributed to this clustering (Clarke, 1993). Monthly species abundance data were fourth root transformed and a triangular matrix of similarities between samples was derived using the Bray-Curtis similarity coefficient. The similarity matrix was then subjected to cluster analysis. Clustering was by hierarchical agglomerative method using group average linking, resulting in a dendrogram . In the resulting dendrogram, the months in the same cluster have more similar species composition than months in different clusters. The contribution of each species to the formation of groupings in the cluster is then analysed by SIMPER procedure. All these analysis were performed using PRIMER v5 (Clarke and Warwick, 1994) software.

C. CORRELATION

First the bivariate correlation of environmental parameters with the biological parameters and phytoplankton density was done. Secondly the correlation between environmental parameters was calculated. The Pearson correlation coefficient was found in both the cases using SPSS (7.5) software.

1.3. RESULTS

1.3.1. PHYTOPLANKTON

1.3.1.1. CHOMBALA

A. QUALITATIVE ANALYSIS

Members of 4 algal classes Bacillariophyceae, Dinophyceae, Cyanophyceae and Rapidophyceae were recorded at Chombala during the study period. Bacillariophyceae was the dominant class both in terms of diversity and abundance. All the other classes were represented by very few species, which in some months bloomed and formed the dominant members of the phytoplankton community. Rapidophyceae was represented by *Chattonella marina* and Cyanophyceae by *Trichodesmium* spp in both the years.

Of the total 63 species of phytoplankton identified in the first year, 81.6% were diatoms, 15 % dinoflagellates, 1.7 % rapidophytes and 1.7 % bluegreens. Diatoms were represented by 31 species of centric diatoms of 20 genera under 6 families and 20 species of pennate diatoms of 12 genera belonging to 3 families. Dinophyceae was composed of 9 species of dinokont dinoflagellates belonging to 6 genera falling in 6 families and a single genus of desmokont dinoflagellate, *Prorocentrum*. In the second year, 75 species of phytoplankton were identified of which 85.3 % were diatoms, 10.7 % dinoflagellates, 1.3% rapidophytes and 1.3% blue greens. Centric diatoms were represented by 45 species of 21 genera coming under 7 families and pennate diatoms by 20 species of 13 genera coming under 3 families. *Prorocentrum* was the only desmokont dinoflagellate, where as the subclass dinokontae was represented by 8 species of 5 genera under 5 families.

Based on the occurrence in monthly samples, the diatoms that were most frequent in the first year were, *Biddulphia mobiliensis (*100%), *Thalassionema nitzschioides* (83.3%), *Biddulphia sinensis* (83.3%), *Coscinodiscus asteromphalus* (75%), *Thalassiosira subtilis* (66.6%), *Ditylum sol* (58.3%), *Asterionella japonica* (66.6%), *Fragilaria oceanica* (58.3%) and *Thalassiothrix frauenfeldii* (58.3%). Among dinoflagellates, *Ceratium furca* was the most frequent with 41.6% followed by *Prorocentrum micans* (33.3%). In the second year, more than 50% occurrence was recorded for the diatoms *Biddulphia mobiliensis* (69.2%), *Thalassionema nitzschioides* (61.5%), *Triceratium favus* (53.8%) and *Nitzschia sigma* (53.8%). Dinoflagellates were less frequent in occurrence. Among the recorded species *Ceratium furca, P.micans, N.scintillans* and *Gymnodinium* sp were more frequent when compared to other species with a total occurrence of 15.4%. The most diverse genera in the first year were *Coscinodiscus* (6 species), *Chaetoceros* (5), *Nitzschia* (5) among diatoms and *Peridinium* (4) among dinoflagellates. In the second year, the genera with the richest species were *Coscinodiscus* (7), *Nitzschia* (6), *Biddulphia* (6), *Chaetoceros* (7) among diatoms and *Peridinium* (5) among dinoflagellates.

The results of the qualitative analysis of phytoplankton at Chombala along with its percentage of occurrence are presented in Table.1.1a. and 1.1b. Fig.1.2a and b presents the percentage composition of the families of diatoms in the first and second year respectively and Fig. 1.3 gives the % composition of the families of dinoflagellates at Chombala for the whole study period.

B. QUANTITATIVE ANALYSIS

Phytoplankton was present at the highest density of 13.5×10^6 cells l^{-1} during the bloom of the rapidophyte *Chattonella marina* in September and the lowest in January with 2148 cells l^{-1}. The densties were also high in May with 28×10^5 cells l^{-1} and in April with 38×10^4 cells l^{-1}. The increased cell density in May was due to bloom of *Pleurosigma normanii* at a density of 26×10^5 cells l^{-1} and in May due to the bloom of *Thalassionema nitzschioides* which was present at a density of 3.7×10^5 cells l^{-1}.

Dinoflagellates which ranked second in importance to diatoms at the station were present in low numbers. It was absent in the samples in the months from November to April and in August and September 2003. During the rest of the period it varied from a lowest of 100 cells l^{-1} in September 2002 to the highest of 4950 cells l^{-1} in May 2003. Cyanophyceae was present in the sample only in January and May. In May a high concentration of 1,29,800 cells l^{-1} was recorded for the class. The results of the quantitative analysis of phytoplankton is presented in Table.1.2 and the variation in phytoplankton density is presented in Fig. 1.4a.

C. DIVERSITY INDICES

The diversity indices-Margalef's species richness, Shannon-Wiener's diversity and evenness were the lowest in September during the bloom of *Chattonella marina* in both the years. In the first year, the total species numbers were the highest in the pre-monsoon months, with the highest in April. In the second year the species numbers were the highest in the monsoon month of July. It was also high in the months of November and in January. The variation in total species numbers and that of dinoflagellates and diatoms are represented graphically in Fig.1.5a.

Table.1.1a. Results of the qualitative analysis of phytoplankton at Chombala from October 2001 to September 2002.

Species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
Class: Bacillariophyta												
Order: Centrales			**Sub order: Discoideae**									
Family: Coscinodisceae												
Sub family: Melosirineae												
Melosira sulcata	0	0	0	0	0	1.5	0	0	0	0	0	0
Sub family:Sceletonemineae												
Skeletonema costatum	0	0	0	5	0	1.5	0.8	0	0.3	1.9	0	0
Thalassiosira subtilis	0	0	20	22.7	1.9	5	8	1.5	1.8	21.6	0.9	0
Sub family : Coscinodiscineae												
Coscinodiscus asteromphalus	0	0	0	0	0	4.5	22.4	65	1.5	4	46.3	13.4
Coscinodiscus excentricus	0	0	0	0	0	0	0	0	0	1.9	0	0
Coscinodiscus janischii	0	0	0	0	0	4.5	0	0	0	33.3	3.8	0
Coscinodiscus perforatus	0	0	0	0	0	0	0	0	0	1.9	0	0
Coscinodiscus sp	0	6.7		0	0	0	0	0	0	0	0	0
Coscinodiscus sub-lineatus	0.74	0	30	0	40	0	0	0	0	5.8	0	0
Coscinodiscus nitidus	0	0	0	0	0	0	4	0	0.6	0	0	0
Cyclotella striata	0	1.67	0	0	0	0	0	0	0	0	0	0
Planktoniella sol	0	0	0	0	0	4.5	0	0.2	0.3	0	0	0
Sub order: Solenoideae												
Family: Solenieae			**Sub Family: Lauderiineae**									
Lauderia annulata	0	0	0	0	0	0	0	0.6	0.3	0	0	0
Schroederella delicatula	0	0	0	0	0	4.5	0	0	0	0	0	0
Leptocylindrus danicus	0	0	0	0	1.9	0	0.8	0.2	0.6	0	0	0
Sub Family: Rhizosoleniinae												
Guinardia flaccida	0	0	0	0	0	0	0	0.2	0	0	0	0
Rhizosolenia alata	0	0	0	6	12.7	23	0.8	0.2	0	0	0	0
Rhizosolenia styliformis	0	0	0	0	0	0	0.8	1.5	0	0	0	0
Sub order: Biddulphioideae												
Family:Chaetocereae												
Bacteriastrum sp	0	0	0	0	0	1.5	0	0	0	0	0	0
Bacteriastrum varians	0	0	0	0	0	0		0	0	0	0	0
Chaetoceros affinis	0	0	0	0	0	0	1.6	0	0	0	0	0
Chaetoceros curvisetus	0	0	0	0	0	0	4	0	0	0	0	0
Chaetoceros lorenzianus	0	0	0	0	0	0	0	0	0	0	0.9	0
Chaetoceros socialis	0	0	0	0	0	0	0.8	0	0	0	0	0
Chaetoceros spp	0	1.7	0	15.1	1.9	0	0	0	0	0	0	0
Chaetoceros coarctatus	1.5	0	0	0	0	0	0	0	0	0	0	0
Family: Biddulphieae												
Sub family:Eucampineae												
Streptotheca thiamensis	0	0	0	0	0	0	1.6	0	0	0	0	0
Sub family: Triceratineae												
Triceratium favus	0	0	0	0	0	0	0.8	1	0.9	7.8	0.9	0
Triceratium sp	0	0	0	0	0	4.5	0	0	0	0	0	0
Ditylum sol	0	0	0	1.25	3.6	4.5	4	0.2	0.9	0	0.9	0
Lithodesmium undulatum	0	0	0	2.5	0	0	0	0	0	0	0	0
Sub family: Biddulphineae												
Biddulphia mobilensis	15.5	16.9	6	3	12.7	10	17.6	5.4	21	9.8	6.5	0
Biddulphia sinensis	0	6.7	1.5	3	7.2	1.5	4	4.36	3.5	4	6.5	0
Family: Hemiaulineae												
Cerataulina bergonii	0	0	0	0	0	0	0	0.2	0	0	0	0
Family: Euodieae												
Hemidiscus hardmannianus	0	0	0	0	1.9	0	0	0	0	0	0	0
Order: Pennales			**Sub order: Araphidineae**									
Family: Fragilariodeae			**Sub family: Tabellarieae**									
Climacosphenia moniligera	0	0	0	0	0	0	0	0.2	1.5	0	0	0
Sub family: Fragilarieae												
Fragilaria oceanica	12.1	1.7	0	2.5	1.9	0	0	0	0	0	0	0
Asterionella japonica	27.2	33	0	0	0	0	4	2.2	60	0	3.7	0
Thalassionema nitzschioides	1.5	1.7	10	33	12.7	4.5	0.8	0	0	0	0	0
Thalassiothrix frauenfeldii	37.8	20.3	0	0	0	1.5	1.6	0	0.3	0	0.9	0
Thalassiothrix longissima	0	0	0	0	0	0	0	0	0	0	0	0

table contd….

Species	Oct	Nov	Dec	Jan	Febr	Mar	April	May	June	July	Aug	Sept
Sub order: Biraphideae												
Family: Naviculoideae			**Sub family:Naviculeae**									
Gyrosigma balticum	0	0	3	0	0	0	0	0	0	0	0	0
Navicula spp	0.74	0	0	0	0	0	0	0.2	0	0	0.9	0
Pleurosigma aestaurii	0	0	0	0	0	0	0	0	0	0	0.9	0
Pleurosigma angulatum	0.74	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma elongatum	0	0	0	0	0	0	0.8	13.5	3	4	6.5	0
Pleurosigma normanii	0	6.7	1.5	0	0	4.5	0.8	0	0	1.9	0.9	1.14
Diploneis spp	0	0	0	0	0	0	0.8	0	0	0	0	0
Sub family: Amphiproroideae												
Amphiprora gigantea	0	0	0	0	0	0	0	0	0	0	0	0
Sub family: Gomphocymbelloideae												
Amphora limbata	0	0	0	0	0	0	0	0	0	0	0	0
Family: Nitzschiaceae			**Sub family : Nitzschioideae**									
Nitzschia lanceolata	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia longissima	0	0	0	0	0	0	8	1.5	1.5	0	0	0
Nitzschia sigma	0	0	0	0	0	0	0	1	0	0	14.8	0.79
Nitzschia spp	0	0	0	0	0	3	0	0	0	0	0.9	0
Nitzschia pungens	0	0	24	2.5	0	0	0	0	0	0	0	0
Nitzschia sp	0	0	0	0	0	0	4	0.4	0.6	0	0	0
Division : PYRROPHYTA												
Class : Dinophyceae												
Sub Class:Dinokontae												
Order : Peridinales												
Family: Ceratiaceae												
Ceratium furca	0	3	0	1.25	0	1.5	0.8	0	0	0	0	0
Family: Peridiniaceae												
Peridinium claudicans	0	0	0	0	0	0	0	0	0.3	0	0	0
Peridinium spp	0	0	0	0	0	4.5	0	0	0	0	0	0
Peridinium conicoides	0	0	0	0	0	0	0.8	0	0	0	0	0
Peridinium cerasus	0	0	0	0	0	0	0.8	0	0	0	0	0
Peridinium elegans	0	0	0	0	0	0	0	0	0.3	0	0	0
Order : Gonyalaucales												
Family: Pyrophacaceae												
Pyrophacus horologium	0	0	3	0	0	0	0	0.2	0	0	0	0
Order : Dinophysiales												
Family : Dinophysiaceae												
Dinophysis caudata	0	0	0	0	1.9	0	0	0	0	0	0	0
Order: Noctilucales												
Family :Noctilucaceae												
Noctiluca scintillans	0	0	0	0	0	0	0	0	0	0	3.7	0.05
Order: Gymnodinales												
Family : Gymnodiniaceae												
Gymnodinium spp	0	0	0	0	0	1.5	0	0	0	0	0	0
Sub Class :Desmokontae												
Order : Prorocentrales												
Family : Prorocentraceae												
Prorocentrum micans	0	0	0	2.5	0	0	1.6	0	0	0	0	0
Prorocentrum lima	0	0	0	0	0	0	1.4	0	0	0	0	0
Division: CYANOPHYTA												
Class: Cyanophyceae												
Order: Oscillatoriales												
Family: Oscillatoriaceae												
Trichodesmium erythraeum	0	0	0	0	0	5		0	0.3		0	0
Division : RAPIDOPHYTA												
Class :Rapidophyceae												
Family: Chattonales												
Chattonella marina	0	0	0	0	0	0	0	0	0	0	0	84.3
Others	2.23	0.02	1	0	0	3	3.2	0.24	0.5	2.1	0.1	0

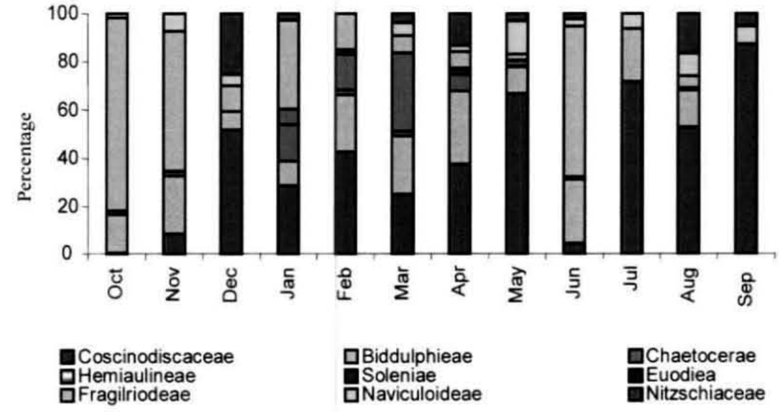


Fig.1.2a.Composition (%) of families of diatoms at Chombala from Oct 01 to Sept 02

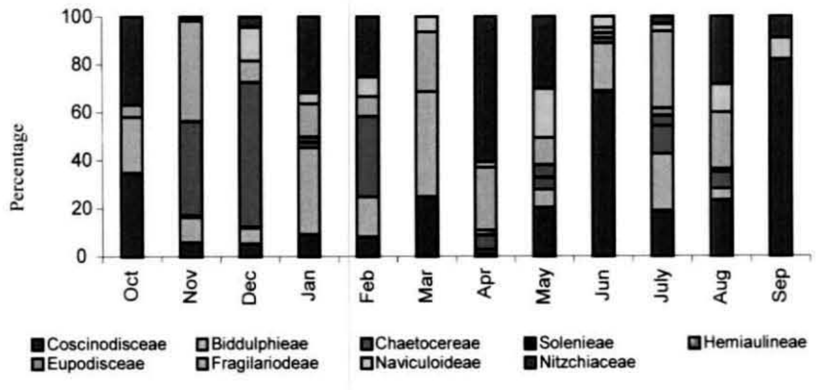


Fig.1.2b. Composition (%) of families of diatoms at Chombala from Oct 02 to Sept 03.

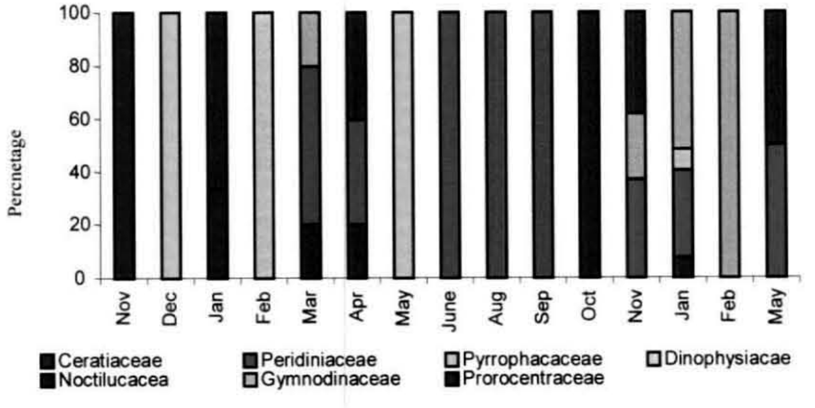


Fig.1.3.Composition (%) of families of dinoflagellates at Chombala from Oct 01 to Sept 03

Species	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Order: Pennales												
Sub order: Araphidineae												
Family: Fragilariodeae												
Sub family: Fragilarieae												
Asterionella japonica	3.1	8.2	0	0	0	0	7	2.4	0	5.8	18.6	0
Fragilaria oceanica	0	0.91	0.43	1.28	0	0	0	0	2.17	13	1.16	0
Thalassionema nitzschioides	1.6	11.4	8.5	6.4	0	0	19	6.1	0	7.2	2.3	0
Thalassiothrix frauenfeldii	0	0	0	0	4.5	25	0	2.4	0	5.8	1.16	0
Sub order: Biraphideae												
Family: Naviculoideae			**Sub family:Naviculeae**									
Navicula clavata	0	0	0	0	0	0	0	0	0	1.45	0	0
Navicula spp	0	0	1.28	0	0	0	1	0	0	0	0	0
Pinnularia spp	0	0	0	1.28	0	0	0	0	0	0	0	0
Pleurosigma elongatum	0	0	11.1	0	4.5	0	0	0	0	0	11.6	0.75
Pleurosigma normanii	0	0	0	1.28	0	0	0	19.5	4.3	1.45	0	0
Pleurosigma angulatum	0	0.45	0	0	0	0	0	0	0	0	0	0
Diploneis weissflogii	0	0	0.43	0	0	0	0	0	0	0	0	0
Diploneis robustus	0	0	0	0	0	0	1	0	0	0	0	0
Mastoglia minuta	0	0	0.85	0	0	6.25	0	0	0	0	0	0
Sub family: Amphiproroideae												
Amphiprora gigantea	0	0	0.43	0	0	0	0	0	0	0	0	0
Sub family: Gomphocymbelloideae												
Cymbella marina	0	18.2	0	0	0	0	0	0	0	0	0	0
Family: Nitzschiaceae			**Sub family : Nitzschioideae**									
Nitzschia panduriformes	0	0	0	0	0	0	0	1.2	0	0	0	0
Nitzschia lanceolata	3.1	0	0	1.28	0	0	13	6.1	0	1.45	1.16	0
Nitzschia longissima	0	0	0	16.6	13.5	0	12	3.7	0		0	0
Pseudo-nitzschia pungens	0	0	0	0	0	0	0	0	0	1.45	23.3	0
Pseudo-nitzschia sp	0	0	0	0	0	0	22	16.3	0	0	0	0
Nitzschia sigma	31.3	0.91	4.2	0	0	0	0	1.2	0	0	3.5	0.75
Nitzschia spp	0	0	0	0	0	0	13	0	0	0	0	0
Division : PYRROPHYTA												
Class : Dinophyceae												
Sub Class:Dinokontae												
Order : Peridinales												
Family: Ceratiaceae												
Ceratium furca	1.6	0	0	2.6	0	0	0	0	0	0	0	0
Family: Peridiniaceae												
Peridinium pentagonum	0	0	0	1.28	0	0	0	0	0	0	0	0
Peridinium variegatum	0	0	0	8.9	0	0	0	0	0	0	0	0
Peridinium spp	0	0	0	1.28	0	0	0	2.4	0	0	0	0
Peridinium conicoides	0	0.45	0	0	0	0	0	0	0	0	0	0
Peridinium cerasus	0	0.91	0	0	0	0	0	0	0	0	0	0
Order : Dinophysiales												
Family : Dinophysiaceae												
Dinophysis acuminata	0	0	0	2.6	0	0	0	0	0	0	0	0
Order: Gymnodinales												
Family :Noctilucaceae												
Noctiluca scintillans	0	0	0	0	0	0	0	0	0	1.45	0	0
Family : Gymnodiniaceae												
Gymnodinium spp	0	0.91	0	17.9	45.5	0	0	4.2	0	0	0	0
Sub Class :Desmokontae												
Order : Prorocentrales												
Family : Prorocentraceae												
Prorocentrum micans	0	1.4	0	0	0	0	0	2.4	0	0	0	0
Prorocentrum lima	0	0	0	0	0	0	0	0	0.4	0	0	0
Division: CYANOPHYTA												
Class: Cyanophyceae												
Order: Oscillatoriales												
Family: Oscillatoriaceae												
Trichodesmium erythraeum	0	0	0	0	0	0	0	0	2.2	0	0	0
Division : RAPIDOPHYTA												
Class :Rapidophyceae												
Family: Chattonales												
Chattonella marina	0	0	0	0	0	0	0	0	0	0	0	91.5
Other algae	4.6	4.25	0.46	9.22	0.3	0	1	0	0.28	0.2	1.06	0

Table.1.1b. Results of the qualitative analysis of phytoplankton at Chombala from Oct 02 to Sept 03.

Species	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Class: Bacillarophyta												
Order: Centrales	**Sub order: Discoideae**											
				Family: Coscinodisceae								
				Sub family: Melosirineae								
Melosira sulcata	0	0	0	0	0	25	0	0	4.3		0	0
				Sub family:Sceletonemineae								
Skeltonema costatum	0	0	0	2.6	0	0	0	0	2.17	0	0	0
Thalassiosira coramandeliana	0	0	0	0	0	0	0	0	2.17	0	0	0
Thalassiosira subtilis	0	0.91	0	1.28	0	0	0	0	0	0	0	0
				Sub family : Coscinodiscineae								
Coscinodiscus asteromphalus	21.9	0	5.1	0	0	0	0	0	0	8.7	23.3	0
Coscinodiscus centralis	0	0	0	0	0	0	0	0	0	2.9	0	0
Coscinodiscus excentricus	0	4.6	0	0	0	0	0	19.5	0	0	0	0
Coscinodiscus gigas	0	0	0	0	0	0	0	0	0	0	0	7
Coscinodiscus janischii	0	0	0	0	0	0	0	0	58.6	0	0	0
Coscinodiscus spp	7.8	0	0	1.28	4.5	0	0	0	0	0	0	0
Coscinodiscus sub-lineatus	0	0	0	0	0	0	0	0	0	7.2	0	0
Coscinodiscus perforatus	0	0	0.43	0	0	0	0	0	0	0	0	0
Planktionella sol	3.1	0	0	0	0	0	0	0	0	0	0	0
				Family: Eupodisceae								
Actinoptychus undulatus	0	0	0	0	0	0	0	0	0	0	1.16	0
Actinoptychus splendens	0	0	0	0	0	0	0	0	2.17	1.45	0	0
Gossleriella tropica	0	0	0	0	0	0	0	0	0	1.45	0	0
				Sub order: Solenoideae								
Family: Solenieae		**Sub Family: Lauderiineae**										
Lauderia annulata	0	0	0	1.28	0	0	0	0	0	0	0	0
Leptocylindrus danicus	0	0.91	0	0	0	0	6	2.4	0	0	0	0
				Sub Family: Rhizosoleniinae								
Guinardia flaccida	0	0	0	0	0	0	0	0	0	0	7	0
Rhizosolenia alata	0	0.91	0	0	0	0	0	0	0	0	0	0
Rhizosolenia stolteforthii	0	34.2	60	0	0	0	0	1.2	0	0	0	0
Rhizosolenia styliformis	0	0	0	0	0	0	0	1.2	2.17	4.3	0	0
Sub order: Biddulphioideae												
				Family:Chaetocereae								
Bacteriastrum delicatulum	0	0	0	0	0	0	0	0	0	1.45	0	0
Bacteriastrum varians	0	0	0	0	0	0	0	0	0	1.45	0	0
Chaetoceros affinis	0	0.91	0	1.28	13.7	0	2	0	0	0	0	0
Chaetoceros curvisetus	0	0	0	0	0	0	0	0	0	1.45	0	0
Chaetoceros decipiens	0	0	0	0	0	0	0	0	0	2.9	0	0
Chaetoceros eibinii	0	0	0	0	0	0	0	2.4	0	0	0	0
Chaetoceros lorenziannus	0	0	0	0	0	0	0	0	0	2.9	0	0
Chaetoceros wighamii	0	0	0	0	4.5	0	0	2.4	0	1.45	0	0
Chaetoceros diversus	0	0	0.43	0	0	0	0	0	0	0	0	0
				Family: Biddulphieae								
				Sub family:Eucampineae								
Streptotheca thiamensis	0	0	0	0	0	0	0	1.2	0	2.9	0	0
Streptotheca indica	0	0.45	0	0	0	0	0	0	0	0	0	0
Eucampia zoodiacus	9.4	0	0	0	0	0	0	0	0	0	0	0
Climacodium fraunfeldii	0	0.91	0	0	0	0	0	0	0	0	0	0
				Sub family: Biddulphineae								
Biddulphia heteroceros	0	0	0	0	0	0	0	1.2	0	0	0	0
Biddulphia mobiliensis	6.3	2.7	5.5	7.6	4.5	18.75	0	0	17.3	10.1	4.7	0
Biddulphia obtusa	0	0	0	8.9	4.5	0	1	0	0	1.45	0	0
Biddulphia pulchellum	0	0	0	0	0	0	0	1.2	2.17	0	0	0
Biddulphia rhombus	0	0	0	0	0	0	0	0	0	1.45	0	0
Biddulphia sinensis	3.1	4.6	0.43	2.6		18.75	0	0	0	1.45	0	0
				Sub family: Triceratineae								
Bellarochea malleus	0	0	0	0	0	0	0	1.2	0	1.45	0	0
Triceratium favus	3.1	0.91	0.43	1.28	0	6.25	0	1.2	0	1.45	0	0
Triceratium reticulum	0	0	0	0	0	0	0	0	0	1.45	0	0
Ditylum sol	0	0	0	0	0	0	0	1.2	0	1.45	0	0
Family: Hemiaulineae												
Hemiaulus hauckii	0	0	0	0	0	0	2	0	0	0	0	0

table contd....

Acknowledgement

It is a great pleasure for me to put on record, a deep sense of gratitude and indebtedness to Dr.V.Kripa, Senior scientist and Supervising guide, Mariculture Division, CMFRI for her guidance, constant encouragement and affectionate advice throughout the tenure of the present study.

I am extremely thankful to Professor (Dr.) Mohan Joseph Modayil, Director, Central Marine Fisheries Research Institute for his inspiring directions and for providing me with all necessary facilities to carry out this research study at the Institute.

I wish to thank Dr. Ammini Joseph, Dean, School of Environmental Sciences, Cochin University of Science and Technology, for her guidance and valuable suggestions during my research study.

I acknowledge my profound gratitude to Dr. C. P. Gopinathan, Principal Scientist, FEM Division, CMFRI for helping me with the identification and classification of phytoplankton, and also for valuable guidance, critical comments and suggestions during my study period and when writing the thesis. I thank Dr. M. Srinath, Head, FRADivision for providing me with the fishery data collected by the division for my study. I also thank Dr. M.K. Mukundan, Head, QAM Division, and Dr. Asokan, QAM Division, Central Institute of Fisheries Technology for analysis of the samples at the Institute and providing me with all the necessary help during my research work.

I wish to express my gratitude to Dr. K. S. SunilKumar Mohammed, Senior Scientist and Head of Molluscan Fisheries Division, Dr. K.K.Appukuttan, Principal scientist, MFD and for their critical advices in carrying out the analysis and writing the manuscript.

I express my sincere thanks to Dr. Somy Kuriakose, Scientist,FRA Duvision for helping in the statistical analysis of the data.

I acknowledge my profound gratitude and sincere thanks to the following eminent scientists for their inspiration, encouragement and for the spontaneous help whenever I needed in various ways. Dr.R. PaulRaj, Scientist in Charge, PGPM, CMFRI, Dr. Shoji Joseph, Scientist (Sr. scale), Mariculture Division, Dr. T. S. Velayudhan, Principal Scientist, MFD, Cochin, and Dr. P. N. Radhakrishnan, Scientist in charge, CRC of CMFRI, Calicut.

I express my thanks to Mr. P. Pavithran, FRA Division for his valuable help in data analysis and also to Mr. P. Radhakrishnan, Technical officer of MFD for his constant help throughout the research period. I also thank Ms. Jenny, H. Sharma, Mr. Mathew Joseph and P.S. Alloycious, technical staff, and Mr. M.N. Satyan, Ms. Ambika, MFD, and Technical officers Ms. Valsala, FEMD, Cochin, Mr. Krishnan, FRA Division, Calicut, for their assistance in field sampling, lab and data analysis. I also thank Mr. Vihwanathan and Mr. Yonus for their help in collecting samples for the present work and for the fishermen for the timely alert they have provided me in case of algal blooms.

I am grateful to my colleague Ms. Sreejaya.R, for her wholehearted co-operation and support rendered during the tenure of my research. I am also thankful to the research scholars, Ms. Sona, Dr. Gireesh, Dr. Balu, Ms. Leena Balu, Ramalinga, Abdu Rahiman, Ms. Smitha, Anjana, AniKumari, Radhika, Unnikrishnan, Daliya, Nita, Shiju and all other students and scholars of CMFRI. I also thank the research scholars Jaleel, and Joyce of CUSAT for their support in various stages of my studies. I also thank Dr. Satish Sahayak, Ms. Preeta for their timely help in carrying out my research work.

I take this opportunity to express my love and affection to my parents, and my family, who have been the motivating factor in all my endeavours. I am especially thankful to my husband Mr. Zanath and his family for their understanding and support.

I am extremely thankful to the Indian council of Agricultural Research (Govt.of India), New Delhi for the award of Research assistantship, during the tenure of which, the present study was carried out.

I am grateful to all staff and students of CMFRI, Cochin and Calicut for their support rendered in various ways during the tenure of my research.

Lastly but not the least, I thank GOD ALMIGHTY for giving me strength and blessings to complete my work.

GENERAL INTRODUCTION

The oceans are home to thousands of microscopic algae, which constitute the base of the marine food web. These phytoplankton are essential for the production of biomass at all levels of the food web and thus play an important role in ocean's ecology. Beneficial phytoplankton blooms defined by Smayda (1997) as –'a significant population increase during which the bloom and the subordinate species within the community have equivalent ecological and physiological valence', are thus intrinsically beneficial to food web processes as they channel carbon or energy into the marine food web. There are however a few dozen of algal species whose blooms are associated with some adverse impacts. According to International Council For the Exploration of Seas (1984), exceptional blooms have been defined as 'those which are noticeable, particularly to the general public, directly or indirectly through their *effects* such as visible discolouration of the water, foam production, fish or invertebrate mortality or toxicity to humans'. These species make their presence known in many ways ranging from massive 'red tides' or blooms of cells that discolour the water to dilute inconspicuous concentration of cells noticed only because of the harm caused by their highly potent toxins. These toxins accumulate in shellfish feeding on these algae, resulting in poisonous syndromes like paralytic (PSP), diarrhetic (DSP), amnesic (ASP) and neurotoxic (NSP) shellfish poisoning in human consumers. Fish may be contaminated as well, causing ciguatera fish poisoning (CFP), which results in human illness or death followed by consumption of such whole fish.

Though algal blooms are natural phenomenon and have occurred throughout the recorded history, recent studies from around the world indicate that they have increased in frequency and geographic distribution over the past few decades. Ho and Hodgkiss (1991) in a review on the red tides in subtropical coastal waters from 1928 to 1989 showed that the number of blooms increased from 1 or 2 every 10 year at the beginning of the period to over 220 between 1980 and 1989. Maclean (1989) has noted a spread of the bloom of the toxic dinoflagellate *Pyrodinium bahamense var. compressa* to new locations in the coastal waters of Philippines, with increased occurrence of human deaths by PSP caused by this species. Increase in frequency of algal blooms have been reported along South African coasts (Horstman, 1981), Dutch coastal waters (Cadee, 1986), Seto inland sea, Japan (Imai and Itoh, 1987), Hong Kong harbour (Lam and Ho, 1989), Black sea (Turkoglu and Koray, 2002), in Chinese coastal waters (Qi *et al.*, 1995) and in the coastal waters of North America (Horner *et al.*, 1997). All these point to a 'global epidemic of algal blooms' as referred to by Smayda (1990). According to Hallegraeff (1995) there has been increased reports of harmful algal bloom (HAB) occurrences world wide, due to increased scientific awareness, improved analytical techniques and also because increased coastal mariculture activities have resulted in regular monitoring of these waters. He also commented that HAB events have been on a rise and has spread to previously pristine waters as a result of eutrophication, unusual climatological conditions, and transport of dinoflagellate cysts in ships ballast water and with shellfish imports.

Exceptional bloom forming species form a very low percentage of the total marine phytoplankton. According to a recent survey conducted by Sournia (1995), only about 200 species (184-207) of the total 4000 known (3365-4024) marine phytoplankton species produce exceptional blooms which constitute only about 5.5- 6.7% of the total. Of these, only 1.8 to 1.9% has been so far identified to be toxic. 73-75% of these toxic species are dinoflagellates followed by diatoms. Rapidophyceae, Cyanophyceae, Prymnesiophyceae, Cryptophyceae, Prasinophyceae, Chlorophyceae and Euglenophyceae, all have members which produce exceptional blooms but their percentage is very low compared to that of the first two. Of the dinoflagellates, four genera, *Alexandrium, Dinophysis, Gymnodinium* and *Prorocentrum* are responsible for majority of the toxic events. New species of toxic algae are being continually added to the list.

World wide approximately 2000 cases of human poisonings, with an overall mortality rate of 15% have been reported to be caused by consumption of fish/ shellfish contaminated with algal toxins (Hallegraeff, 1995). Paralytic shellfish poisoning (PSP) produced by dinoflagellates of the genera *Alexandrium, Gymnodinium* and *Pyrodinium* which was until 1970 known only from temperate waters of Europe, North America and Japan has at present been reported from throughout the southern hemisphere in South Africa, Australia, New Zealand, India, Thailand, Brunei, Sabah, Phillippines and Papua New Guinea (Hallegraeff, 1995). The dinoflagellate *Pyrodinium bahamense var. compressa* has been associated with severe PSP outbreaks in South East Asia (Maclean, 1987). In addition to PSP production, they have also been reported to be responsible for fish and shellfish mortalities (Shumway, 1990). Diarrhetic shellfish poisoning (DSP) reported for the first time in the late 1970's from the dinoflagellate *Dinophysis fortii* in Japan (Yasumoto *et al.*, 1978), has been at present reported from South America, New Zealand, Australia, Thailand, Europe, Chile, Canada and possibly Tasmania and New Zealand (Van Dolah, 2000). It may be more widespread in occurrence since the symptoms are very similar to that of the common bacterial gastroenteritis. Production of DSP toxins has been confirmed in

Table.1.2. Results of the quantitative analysis of phytoplankton at Chombala from Sept 2002-Sept 2003.

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Coscinodiscus asteromphalus	27700	1500	0	536	0	0	0	0	0	0	0	800	0
Coscinodiscus excentricus	0	0	1725	1071	376	0	0	0	550	0	0	0	0
Coscinodiscus spp	0	0	0	0	693	533	0	1600	0	0	2428	0	0
Coscinodiscus janischii	0	0	0	0	0	0	0	0	0	7800	0	0	0
Coscinodiscus gigas	0	0	0	0	0	0	0	0	0	0	0	0	1000
Triceratium favus	0	0	720	0	0	0	400	0	0	185	1285	0	0
Biddulphia heteroceros	0	143	0	1785	0	0	0	0	0	0	0	0	0
Biddulphia mobilensis	0	0	720	0	0	0	4500	0	550	557	1714	0	0
Biddulphia sinensis	0	71	1225	0	0	0	2125		0	0	142	0	0
Eucampia sp	0	71	0	0	0	0	0	0	0	0	0	0	0
Rhizosolenia stolteforthi	0	1500	8450	0	0	0	0	0	0	0	0	0	0
Rhizosolenia robusta	0	0	0	0	141	0	0	0	0	0	0	0	0
Rhizosolenia alata	0	0	0	0	0	0	0	0	0	0	142	0	0
Melosira sulcata	0	0	0	0	0	0	42225	0	0	0	285	0	0
Cymbella marina	0	0	4225	0	0	0	0	0	0	0	0	0	0
Thalassiosira coramandeliana	0	0	0	0	0	0	0	800	4950	0	0	0	0
Planktionella sol	0	0	0	0	0	0	0	0	0	0	571	0	0
Ditylum sol	0	0	0	0	0	0	0	0	0	0	142	0	0
Navicula clavata	0	0	0	0	0	0	0	0	0	185	142	0	0
Amphiprora gigantea	0	71	0	0	0	0	0	0	550	0	0	0	0
Pleurosigma angulatum	0	214	0	0	0	0	0	0	0	371	0	0	0
Pleurosigma elongatum	0	0	0	0	0	266	120	0	3300	0	142	21142	100
Pleurosigma normanii	2300	0	0	0	47	0	0	0	2640000	0	0	0	0
Nitzschia spp	0	850	0	0	0	0	0	0	0	0	0	0	0
Nitzchia sigma	1600	645	0	0	0	266	0	0	0	0	0	0	100
Nitzschia longissima	0	0	0	0	0	2666	0	0	19250	0	0	0	0
Nitzschia pungens	0	0	0	0	0	0	0	4000	550	0	0	0	0
Nitzschia lanceolata	0	0	0	0	0	0	0	800	2750	0	142	0	0
Nitzschia panduriformes	0	0	0	0	0	0	0	0	550	0	0	0	0
Grammatophora undulata	0	71	0	0	47	0	0	0	0	0	0	0	0
Fragilaria oceanica	0	0	0	179	0	266	0	0	2200	185	285	0	0
Asterionella japonica	0	71	2240	0	0	0	0	0	0	0	0	0	0
Thalassionema nitzschiodes	0	1285	4225	0	0	0	0	375600	2200	0	0	0	0
Thalassiothrix frauenfeldii	0	0	0	24107	0	12000	88500	0	0	0	857	0	0
Mastoglia minuta	0	0	0	0	0	0	2125	0	0	0	0	0	0
Diploneis robusta	0	0	0	0	0	0	0	0	0	185	0	0	0
Cocconeis sigmoides	0	0	0	0	0	266	0	0	0	0	0	0	0
Diatoms	**31600**	**6492**	**23530**	**27678**	**1304**	**16263**	**139995**	**382800**	**2677400**	**9468**	**8277**	**21942**	**1200**
Gymnodinium spp	0	0	0	0	420	1280	0	0	3850	0	0	0	0
Noctiluca scintillans	100	0	0	0	0	0	0	0	0	0	142	0	0
Peridinium spp	0	214	0	179	283	0	0	0	1100	0	0	0	0
Prorocentrum micans	0	71	0	0	0	0	0	0	0	0	0	0	0
Prorocentrum lima	0	0	0	0	0	0	0	0	0	185	0	0	0
Dinoflagellates	**100**	**285**	**0**	**179**	**703**	**1280**	**0**	**0**	**4950**	**185**	**142**	**0**	**0**
Blue green algae	**0**	**0**	**0**	**0**	**141**	**0**	**0**	**0**	**129800**	**0**	**0**	**0**	**0**
Chattonella marina	**170000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**13500000**
Others	0	2350	0	0	0	0	0	0	0	0	0	0	0
Total	**201700**	**9127**	**23530**	**27857**	**2148**	**17543**	**139995**	**382800**	**2812150**	**9653**	**8419**	**21942**	**13501200**

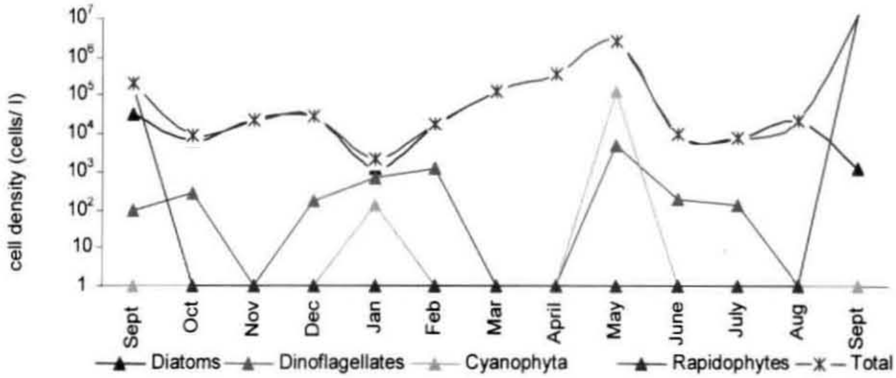


Fig.1.4a.

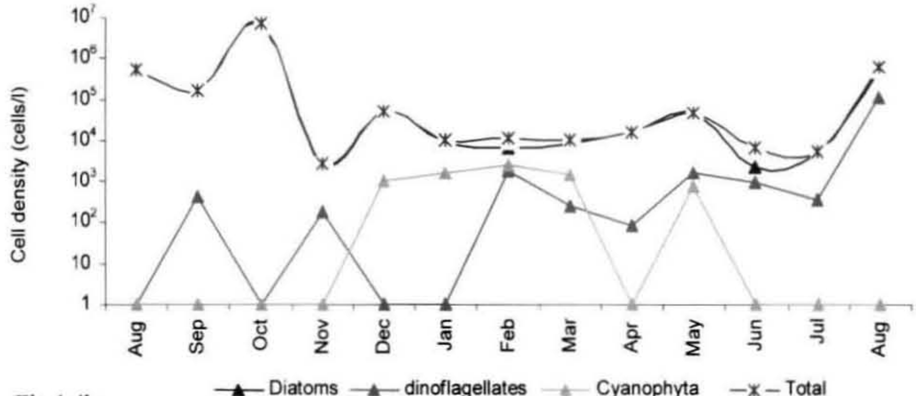


Fig.1.4b.

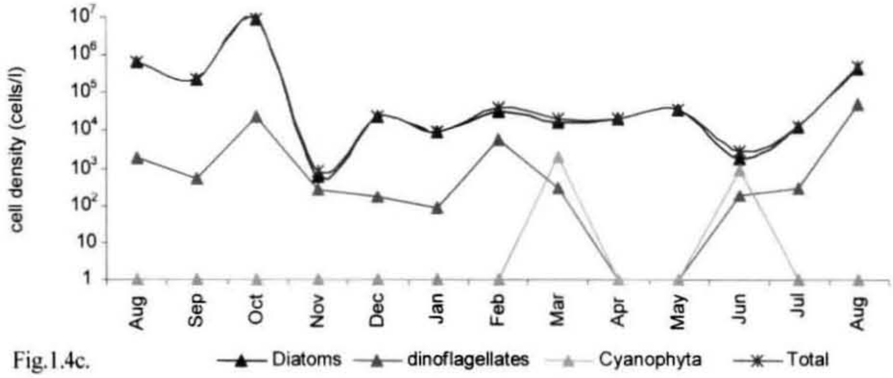


Fig.1.4c.

Fig.1.4a. Variation in cell density of major phytoplankton groups at (a). Chombala from September 2002 to September 2003 and at (b) Vizhinjam sea (c) Vizhinjam bay from Sept 2002 to August 2003

In the first year, species richness was the highest of 5.85 in April with a diversity of 2.70. The diversity and evenness were however the highest in March, with a value of 2.79 and 0.90 respectively. Both diatom and dinoflagellate diversity were also the highest in these months.

In the second year, the species richness and diversity were high in July with values of 6.3 and 3.07, which was mainly contributed by diatoms. Evenness was also the highest in July with a value of 0.90. The dinoflagellate diversity was the highest in January with a value of 1.32. The variation in Shannon-Wiener's diversity during the study period is given in Fig. 1.5b and that of richness and evenness in Fig. 1.5c. The results of the analysis of diversity indices are presented in Table. 1.3.

D. MULTIVARIATE ANALYSIS OF THE PHYTOPLANKTON COMMUNITY STRUCTURE OF THE REGION

Cluster analysis revealed the presence of four distinct clusters in the first year at 35 % similarity. The month of September formed a distinct first Cluster, Cluster II consisted of the pre-monsoon months of January, February, December and March, Cluster III, the post-monsoon months of October and November and Cluster IV consisted of the late pre-monsoon and the monsoon months of April, May, June, July and August.

The results of SIMPER analysis showed that in the first cluster, the major species were all pennate diatoms. In the second cluster, there is a dominance of centric diatoms over pennate diatoms and in the third cluster both pennate and centric diatoms have almost equal importance in the phytoplankton community. In cluster IV, the phytoplankton community is dominated by a species which is from an entirely different class, the rapidophyte *Chattonella marina*. The diatom *Biddulphia mobiliensis* was present in the community in all the seasons.

In the second year, the higher diversity resulted in a lesser percentage of similarity between the months. However, there were three clusters at 25% similarity. SIMPER analysis showed that Cluster I consisted of the month of September alone, Cluster II consisted of the months of March and June and Cluster III consisted the months of January, February, April, May, July and August. Cluster I was dominated by *Chattonella marina* and Cluster II by the centric diatoms, *Biddulphia mobiliensis* and *Melosira sulcata.* Cluster III consisted of both centric and pennate diatoms. The dendogram showing the four clusters of first year is given in Fig. 1.6a and that of the second year in Fig. 1.6b. The results of SIMPER analysis is given in Table. 1.4a and b.

Table. 1.3. Phytoplankton diversity indices at Chombala from October 2001 to September 2003

Months	Species Numbers			Shannon Wiener's			Margalef's	Pileou's
	Total	Diatom	Dinoflagellate	Total	Diatom	Dinoflagellate	Richness	Evenness
Oct	9	9	0	1.51	1.51	0.00	1.75	0.69
Nov	12	10	1	1.99	1.83	0.00	2.37	0.80
Dec	10	8	1	1.85	1.68	0.00	1.95	0.80
Jan	14	11	2	2.08	1.88	0.64	2.80	0.79
Feb	13	11	1	1.96	1.85	0.00	2.60	0.77
March	22	17	3	2.79	2.50	0.95	4.52	0.90
April	28	23	4	2.70	2.51	1.33	5.85	0.81
May	22	20	1	1.39	1.36	0.00	4.56	0.45
June	21	17	2	1.45	1.37	0.69	4.34	0.48
July	12	12	0	2.00	2.00	0.00	2.40	0.80
Aug	18	16	1	2.01	1.83	0.00	3.66	0.70
Sept	6	3	1	0.51	0.46	0.00	1.09	0.28
Oct	12	11	1	2.01	1.96	0.00	2.41	0.81
Nov	21	17	4	2.12	1.98	1.32	4.38	0.70
Dec	15	15	0	1.47	1.47	0.00	3.04	0.54
Jan	21	15	6	2.55	2.23	1.32	4.44	0.84
Feb	9	8	1	1.74	1.93	0.00	1.74	0.79
March	6	6	0	1.67	1.67	0.00	1.09	0.93
April	12	12	0	2.09	2.09	0.00	2.39	0.84
May	23	21	2	2.55	2.45	0.69	4.78	0.81
June	11	10	0	1.47	1.40	0.00	2.17	0.61
July	30	29	1	3.07	3.04	0.00	6.30	0.90
Aug	12	12	0	1.99	1.99	0.00	2.39	0.80
Sept	4	3	0	0.34	0.59	0.00	0.65	0.25

E. BIOLOGICAL PARAMETERS

Seasons were classified as monsoon (June –September), post-monsoon (October-January) and pre-monsoon (February-May). The seasonal values and standard deviation of biological parameters is presented in Table. 1.5.

i) Productivity

Lowest gross productivity (GP) values of 0.789 and 1.04 gC/m^3/day were recorded in December in the first and second years respectively. Maximum value of gross productivity was recorded as 4.83 gC/m^3/day in August the first year and 5.54 gC/m^3/day in September the second year. Net productivity (NP) also showed a similar trend to that of GP. During the first year, it ranged between 0.395 gC/m^3/ day in November and December to a maximum of 2.91 gC/m^3/day in August. In the second year it ranged between lowest of 0.946 in August to the highest of 5.25 gC/m^3/ day in September.

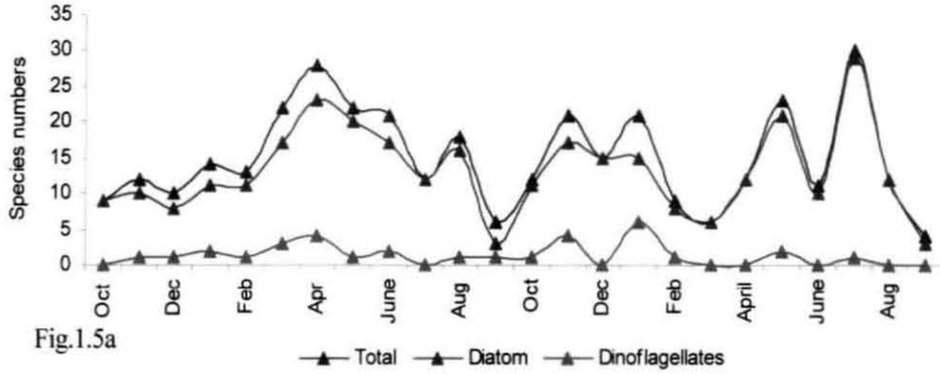


Fig.1.5a

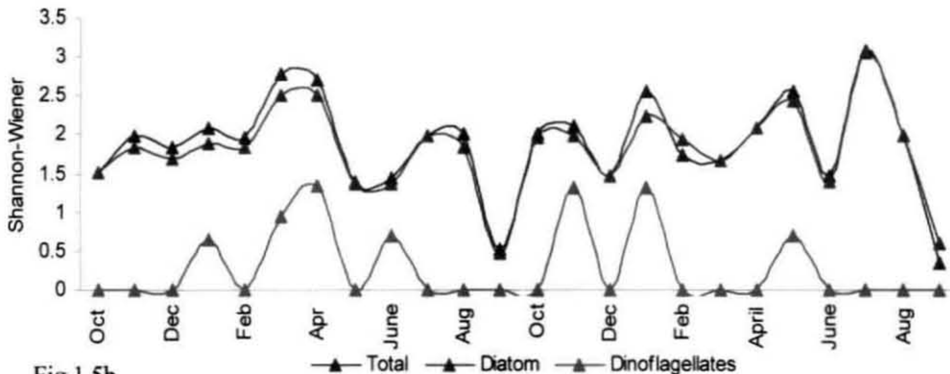


Fig.1.5b

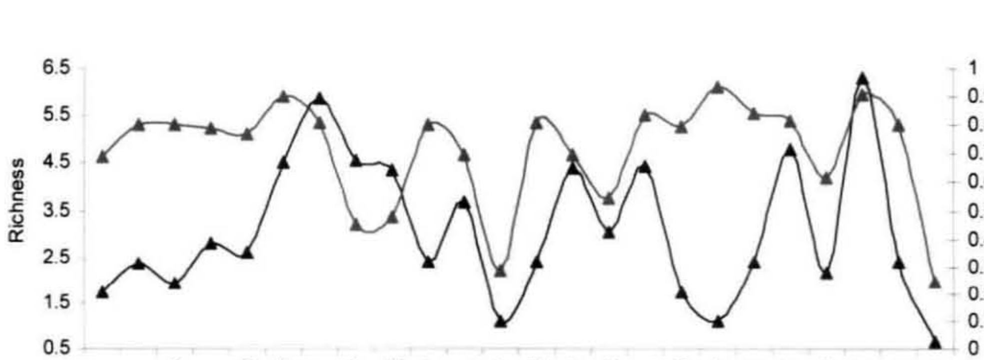


Fig.1.5c.

Fig.1.5. Variation in (a) Species numbers (b) Shannon- Wiener's diversity (c) Richness and evenness at Chombala from Oct 01 to Sept 03.

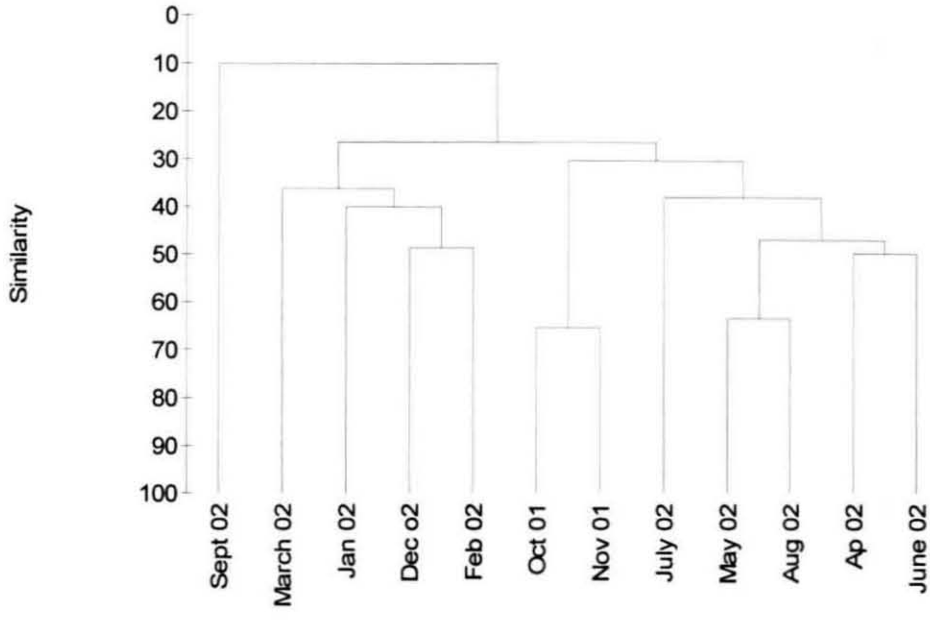


Fig.1.6a. Dendrogramı for hierarchial clustering of the months based on species abundance at Chombala, from October 2001 to September 2002

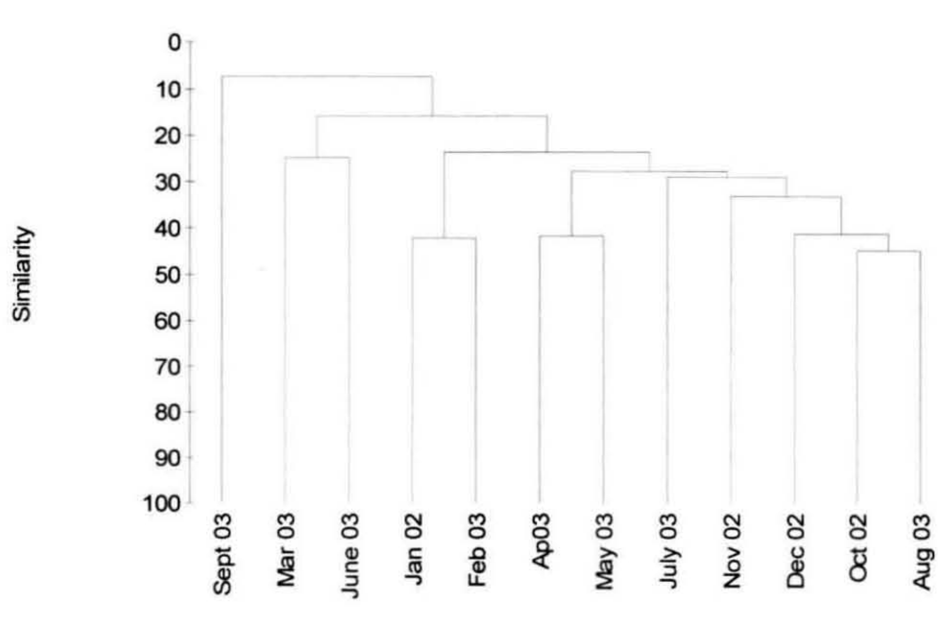


Fig. 1.6b. Dendrogram for hierarchial clustering of the months based on species abundance at Chombala, from October 2002 to September 2003

Table. 1.4a. Results of the analysis of species contribution to the average similarity (SIMPER) within each cluster at Chombala for the period from October 2001 to September 2002.

Species	Avg. abundance	Avg. similarity	Sim/Std. Dev	Contribution%	Cumulative %
Group I (Sept 02)					
Less than 2 samples in group					
Major species -*Chattonella marina*					
Group II (Jan, Feb, Dec, March)					
Average similarity: 42.75					
Thalassionema nitzschioides	15.05	8.42	3.35	19.7	19.7
Biddulphia mobilensis	7.93	7.41	5.57	17.33	37.03
Thalassiosira subtilis	12.39	7.34	2.57	17.16	54.19
Biddulphia sinensis	3.3	8.79	4.58	13.55	67.74
Coscinodiscus gigas	18.63	4.42	0.78	10.35	78.09
Ditylum sol	2.34	2.65	0.9	6.19	84.29
Rhizosolenia styliformis	8.93	1.29	0.41	3.02	87.31
Fragilaria oceanica	1.09	1.08	0.41	2.53	89.83
Chaetoceros affinis	4.24	1.08	0.41	2.53	92.36
Group II (Oct01, Nov 01)					
Average similarity: 63.91					
Asterionella japonica	30.1	15.27	-	23.9	23.9
Thalassiothrix frauenfeldii	29.05	14.19	-	22.21	46.11
Biddulphia mobilensis	16.2	13.27	-	20.76	66.87
Fragilaria oceanica	6.89	7.6	-	11.89	78.76
Thalassionema nitzschioides	1.57	7.37	-	11.53	90.3
Group IV (April, May, June, July, august)					
Average similarity: 49.74					
Biddulphia mobilensis	12.06	7.2	7.75	14.47	14.47
C. asteromphalus	27.84	6.78	2.89	13.63	28.1
Biddulphia sinensis	4.47	6.14	7.42	12.34	40.45
Pleurosigma elongatum	5.56	5.46	3.18	10.97	51.41
Thalassiosira subtilis	6.76	4.86	5.55	9.83	61.24
Triceratium favus	2.28	4.25	6.63	8.54	69.78
Asterionella japonica	13.98	3.26	1.14	6.55	76.32
Ditylum sol	1.2	2.04	1.12	4.1	80.42
Nitzschia longissima	2.2	1.33	0.62	2.67	83.09
Pleurosigma normanii	0.72	1.21	0.61	2.43	85.51
Skeletonema costatum	0.6	1.01	0.61	2.02	87.53
Nitzschia seriata	1	0.98	0.62	1.98	89.51
Thalassiothrix frauenfeldii	0.56	0.97	0.61	1.96	91.47

Table. 1.4b. Results of the analysis of species contribution to the average similarity within each cluster at Chombala for the period from October 2002 to September 2003.

Species	Avg. abundance	Avg. similarity	Sim/Std. Dev	Contribution%	Cumulative %
Group I (September)					
Less than 2 samples in group					
Major species -*Chattonella marina*					
Group II (March and June)					
Average similarity: 24.87					
Biddulphia mobiliensis	18.03	14.58	58.61	58	61
Melosira sulcata	14.65	10.29	41.39	100	0
Group III (January, February, April, May. July, August)					
Average similarity: 28.73					
Thalassionema nitzschioides	6.94	4.59	1.7	15.96	15.96
Biddulphia mobilensis	4.6	3.76	1.11	13.07	29.03
Asterionella japonica	5.01	2.43	0.8	8.46	37.5
Nitzschia sigma	6.01	2.38	0.76	8.29	45.79
Nitzschia lanceolata	2.9	1.93	0.79	6.71	52.51
Triceratium favus	0.93	1.54	0.82	5.34	57.85
Nitzschia longissima	5.09	1.25	0.42	4.33	62.18
Coscinodiscus asteromphalus	6.56	1.24	0.42	4.33	66.51
Biddulphia sinensis	1.35	1.15	0.59	4.01	70.52
Fragilaria oceanica	1.86	1.02	0.6	3.54	74.06
Chaetoceros affinis	1.99	0.82	0.43	2.86	76.92
Thalassiothrix frauenfeldii	1.54	0.79	0.43	2.75	79.67
Biddulphia obtusa	1.76	0.78	0.42	2.71	82.38
Pleurosigma elongatum	3.02	0.74	0.3	2.58	84.96
Nitzschia seriata	4.64	0.58	0.29	2.03	86.99
Rhizosolenia stolteforthii	10.6	0.53	0.26	1.85	88.84
Coscinodiscus sp	1.51	0.51	0.28	1.77	90.6

Both gross and net productivity recorded the lowest values in the pre-monsoon season the first year and maximum in the monsoon season. In the second year, lowest GP and NP values were recorded in the post-monsoon and highest in the monsoon season. The monthly variation of Gross productivity at Chombala and Vizhinjam is presented in Fig. 1.7 and net productivity in Fig.1.8.

ii) Chlorophyll

Chlorophyll (Chl) *a,* the major pigment present in marine phytoplankton, exhibited a similar trend to that of productivity values. In the first year of the study, it ranged between a minimum of 2.8 mg m^{-3} in November to a maximum of 148.2 mg m^{-3} in August. In the second year it ranged between 3.19 mg m^{-3} in December to 370.2 mg m^{-3} in September. Chlorophyll *b* was absent in June and August the first year and recorded a maximum value of 2.16 mg m^{-3} in July 2002. In the second year, Chlorophyll *b* was absent in December and September while the highest value of 4.71 mg m^{-3} was recorded in June. Chlorophyll *c* recorded was minimum of 0.469 mg m^{-3} in February and maximum of 20.15 mg m^{-3} in August the first year. In the second year it ranged between 0.641 in December to a maximum of 78.68 mg m^{-3} in September. The accessory photosynthetic pigments, the carotenoids ranged in concentration between a minimum of 0.171 mg m^{-3} in May and a maximum of 1.9 mg m^{-3} in March, during the first year of study. In the second year of study, carotenoids were absent in March and were high of 3.19 mg m^{-3} in September.

Seasonally, the lowest values were in the post-monsoon season for chlorophyll *a, b, c* and carotenoids. Highest were in monsoon for chlorophyll *a, c* and carotenoids. For chlorophyll *b* highest seasonal value was recorded in pre-monsoon. In the second year, lowest seasonal value for chlorophyll *a, b c* and carotenoids was in pre-monsoon and maximum in the monsoon season. The higher standard deviation in monsoon season in the second year was due to the high chlorophyll values recorded in September 2003 during the bloom of *Chattonella marina. The* monthly variation of Chlorophyll *a* at Chombala and Vizhinjam is presented in Fig. 1.9.

F. BIOTIC CORRELATIONS

Gross and net productivity were positively correlated (r=0.885) which in turn showed significant positive correlation with Chl *a* (r=0.708 and 0.833) and carotenoids (r=0.651 and 0.723). GP showed positive correlation with Chl *c* (r=0.666) and TSS (r=0.422). NP was also related positively to phosphate (r=0.47). Chl *a* and *c* showed positive correlation (r=0.986). Both Chl *a* and *c* showed positive correlation with carotenoids (r=0.872 and 0.85) and phosphate (r=0.612 and r=0.562). Phytoplankton density showed positive correlation with GP (0.777), NP (r=0.942), Chl *a* (r=0.975), Chl *c* (r=0.978) carotenoids (r=0.916) and with phosphate (r=0.65). The results of the correlation analysis are presented in Table.1.6. The parameters which showed significant correlation and the values are presented.

Table.1.5. Seasonal values and standard deviation of biological parameters at Chombala from October 2001 to September 2003

Month	Productivity		Chlorophyll			
	GP	NP	*a*	*b*	*c*	Carotenoids
Units	gC/m^3/day)		mg m^{-3})			
Post M I						
Average	2.18±1.61	1.36±1.26	5.78±3.4	0.76±0.68	2.74±1.04	0.38 ± 0.26
Pre M I						
Average	1.92 ±0.55	1.07± 0.43	13.24 ±16.06	0.97 ±0.78	2.99 ±2.8	0.62 ±0.85
Monsoon I						
Average	2.71± 1.52	1.37± 1.1	54.75± 62.47	0.88 ±1.07	7.49± 8.59	0.86 ±0.7
Post M II						
Average	1.85± 0.9	1.08 ±0.24	12.32± 8.4	0.88 ±0.75	2.32 ±1.75	0.34±0.25
Pre M II						
Average	1.67 ±0.97	1.53 ±0.34	10.85± 6.62	0.64±0.53	2.15± 1.45	0.11 ±0.08
Monsoon II						
Average	2.67± 1.95	2±2.16	108.8±174.9	1.94±2.03	22.6±37.5	1.16±1.4

Table.1.6. Results of Pearson correlation analysis between environmental and biological parameters at Chombala

	GP	NP	Chl a	Chl b	Chl c	Carotenoids	Phytodensity
GP			0.708**		0.666**		0.777*
NP	0.885**		0.833**		0.83**		0.942**
Chlorophyll *a*	0.708**	0.833**					0.975**
Chlorophyll *c*	0.666**		0.986**				0.978**
Carotenoids	0.651**	0.723**	0.872**		0.85**		0.916**
Nitrate				0.605**			
Phosphate		0.474*	0.612**		0.562**	0.511*	0.65**
Rainfall				0.503*			
TSS	0.422*						

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (1- tailed)

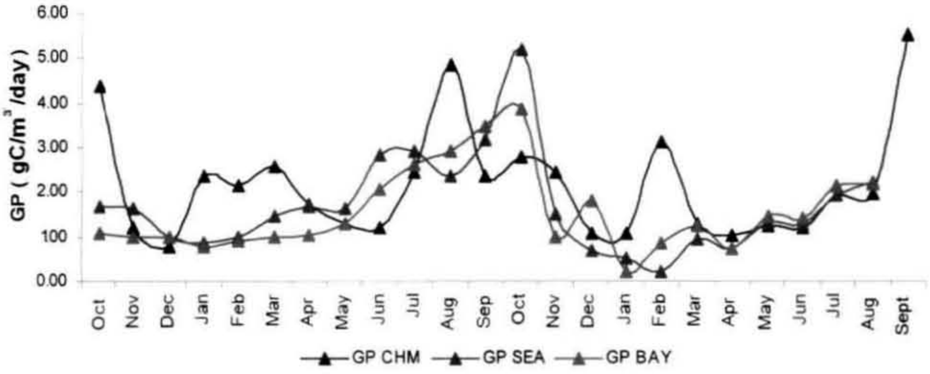


Fig. 1.7. Variation in Gross productivity at the three stations from October 2001 to September 2003.

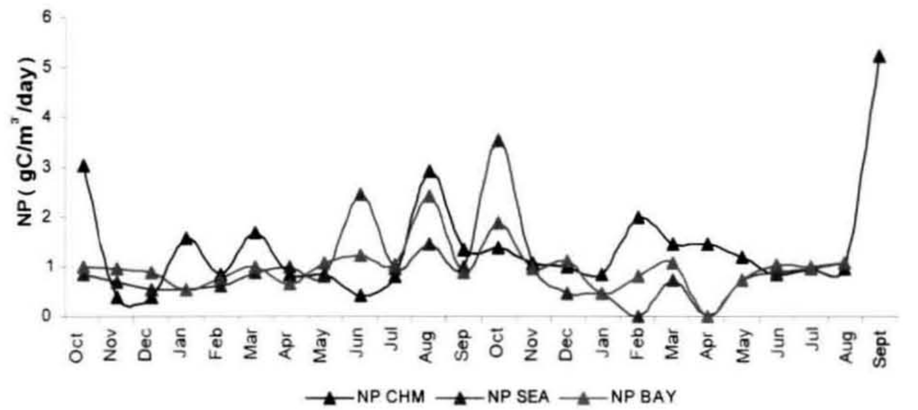


Fig. 1.8. Variation in net productivity at the three stations from October 2001 to September 2003.

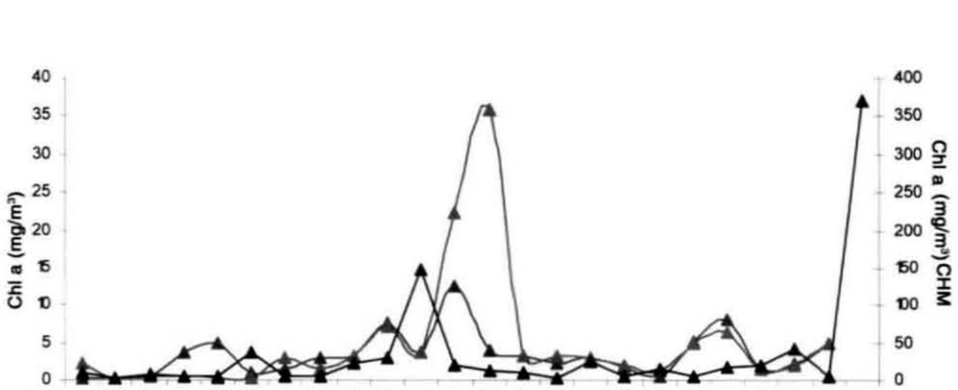


Fig. 1.9. Variation in Chlorophyll *a* at the three stations from October 2001 to September 2003.

1.3.1.2. VIZHINJAM

A. QUALITATIVE ANALYSIS

During the study period from October 2001 to August 2003, phytoplankton belonging to three algal classes, Bacillariophyceae, Dinophyceae and Cyanophyceae were identified in the stations in Vizhinjam bay and sea. Bacillariophyceae was the dominant class, both in terms of species number and abundance followed by Dinophyceae.

Of the total 89 species recorded in the first year in the sea, 69.2 % were members of Bacillariophyceae, 29.6 % belonged to Dinophyceae and 1.1 % to Cyanophyceae. In the first year, of the total 63 diatoms, 43 species were centric diatoms of 18 genera belonging to 6 families and 20 species were pennate diatoms of 12 genera falling under 3 families. Dinophyceae was represented by a single species of desmokont dinoflagellate *Prorocentrum micans* both the years and 27 species of dinokont dinoflagellates of 5 genera falling under 4 families in the first year. In the second year, of the 89 species of phytoplankton, 82 % were members of Bacillariophyceae, 16.9 % belonged to Dinophyceae and 1.1 % to Cyanophyceae. Centric diatoms were represented by 53 species of 21 genera coming under 6 families and pennate diatoms by 21 species of 15 genera coming under 3 families. There were 15 species of dinokont dinoflagellates of 8 genera under 6 families. Cyanophyceae was represented by a single genus of *Trichodesmium* at both the sites.

Of the 88 species of phytoplankton identified from the bay during the first year, 60.2% belonged to Bacillariophyceae, 38.63 % to Dinophyceae and 1.1% to Cyanophyceae. Centric diatoms comprised 38 species of 18 genera coming under 6 families and pennate diatoms comprised 15 species of 10 genera belonging to 3 families. Dinoflagellates were represented by 2 subclasses, a single species of the desmokont dinoflagellate *Prorocentrum micans* and 34 species of dinokont dinoflagellates of 7 genera coming under 5 families. In the second year, of the total 95 species, 72 % of them were members of Bacillariophyceae, 27.4 % Dinophyceae and 1% belonged to Cyanophyceae. Centric diatoms were represented by 51 species of 18 genera belonging to 5 families and pennate diatoms by 17 species of 11 genera belonging to 3 families. Dinophyceae was represented by the desmokont *P.micans* and 24 species of 7 genera of dinokont dinoflagellates coming under 6 families.

Considering the frequency of occurrence, the species that were most common in occurrence in the bay in the first year were the diatoms *Triceratium favus* (83.3%), *Rhizosolenia* *alata* (66.6%), *Biddulphia mobiliensis* (58.3%), *Chaetoceros curvisetus* (41.6%) and the dinoflagellates *Dinophysis caudata* (58.3%) and *Dinophysis miles* (41.6%). The second year it was *Thalassiothrix frauenfeldii* (100%), *Biddulphia mobiliensis* (90.9%), *Triceratium favus* (90.9%), *Biddulphia sinensis* (81.8%), *Bellarochea malleus* (63.6%), *Ditylum sol* (54.5%) and *Thalassionema nitzschioides (*54.5%) among diatoms and *Peridinium* (72.7%), *Dinophysis caudata* (54.5%) and *Ceratium furca* (45.4%) among dinoflagellates.

Species with more than 50% of occurrence in the sea were the diatoms *Triceratium favus* (83.3%), *Biddulphia mobiliensis* (58.3%), *Chaetoceros curvisetus* (50%), *Coscinodiscus sublineatus* (50), *Rhizosolenia styliformis* (50%) and the dinoflagellates *Dinophysis caudata* (50%) in the first year and *Triceratium favus* (72.7%), *Biddulphia mobiliensis* (63.4%), *Chaetoceros curvisetus* (81.8%), *Chaetoceros lorenzianus* (63.4%), *Ditylum sol* (54.5%), *Rhizosolenia alata* (81.8%), *Thalassiothrix frauenfeldii* (63.6%), *Peridinium* (63.6%) and *Dinophysis caudata* (54.5%) in the second year.

The results of the qualitative analysis of phytoplankton along with its percentage of occurrence at Vizhinjam sea is presented in Table. 1.7a and b and that of bay in Table. 1.8a and b.

Fig.1.10a and b presents the percentage composition of the families of diatoms and Fig. 1.11a and b gives the % composition of the families of dinoflagellates at Vizhinjam sea for the study period. Fig.1.12a and b presents the percentage composition of the families of diatoms and Fig.1.13.a and b gives the % composition of the families of dinoflagellates at Vizhinjam bay for the study period.

B. QUANTITATIVE ANALYSIS

In the sea, phytoplankton density showed a major peak in October and minor peaks in August 2002 and 2003 and in December 2002 and May 2003. The major peak in August 2002 was due to the bloom of *Fragilaria oceanica* at a cell density of 46 x 10^4 cells l^{-1}. In October 2002, there was a major bloom of *Chaetoceros curvisetus* with cell density as high as 70 x 10^5 cells l^{-1}. It reduced to 2596 cells l^{-1}, the lowest recorded for Vizhinjam sea in the following month. There was also a decrease from a high density of 47250 cells l^{-1}in May to 4920 cells l^{-1}in July. Cell density of Bacillariophyceae, the dominant class, varied from a minimum of 2160 cells l^{-1} in June 2003 to a maximum of 72,46,000 cells l^{-1} in October 2002. The cell density of dinoflagellates varied from 82 in April to 1,02,000 cells l^{-1} in August 2003.

Table. 1.7a. Results of the qualitative analysis of phytoplankton at Vizhinjam sea from Oct 01 to Sept 02

Species	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Class: Bacillariophyta												
Order: Centrales			**Sub order: Discoideae**									
Family: Coscinodisceae												
Melosira sulcata	0	15.8	0	0	0	0	0	8.2	3.8	4.7	0.38	0
Stephanopyxis palmeriana	0	0	0	0	0	2.1	0	0	0	0	0.38	0
Thalassiosira subtilis	0	0	0	0	42.2	10.8	0	0	0	0	0	0
Skeletonema costatum	0	0	0	0	0	0	0.82	0	0	4.2	0.38	0
Coscinodiscus asteromphalus	2	5.3	1.8	6.8	0	0	9.9	0	0	0	2.3	48.4
Coscinodiscus sublineatus	0	0	0	6.45	0	0	0	0	4.2	7	11.3	0
Family: Eupodisceae												
Actinoptychus splendens	0	1.8	0	11.29	0	0	0	0	0	0	0.38	0
Actinoptychus undulatus	1.3	0	0	0	0	0	0	0	0	0	0	0
Sub order: Solenoideae												
Family: Solenieae												
Leptocylindrus danicus	0	0	0	0	0	0	0.82	2.4	0	0	0.38	0
Rhizosolenia alata	0.67	3.5	30.3	0	2.6	0	0.82	0.6	4.2	2.34	0	0
Rhizosolenia castracanei	0	0	0	0	2.6	0	0	0	0	0	0	0
Rhizosolenia crassispina	0	3.5	0	0	0	0	0	0	0	0	0	0
Rhizosolenia spp	0	0	0	0	0	21.4	0	0	0	0	0	0
Rhizosolenia styliformis	19.5	0	0	0	4.8	0	2.48	0.6	0	0.46	0	2.4
Rhizosolenia imbricata	0	8.8	0	0	0	0	0	0	0	0	0	0
Sub order: Biddulphioideae												
Family:Chaetocereae												
Bacteriastrum elegans	0	0	0	0	0	0	0.82	0	0		0	0
Bacteriastrum hyalinum	0	0	0	0	0	0	0	0	0	1.86	0	0
Bacteriastrum obtusa	0	0	0	0	0	0	0	0	0	0.9	0	0
Bacteriastrum rhombus	0	0	0	0	0	0	0	0	0	0.46	0	0
Chaetoceros affinis	0	1.8	0	0	0	0	4.13	1.2	0	0	0	0
Chaetoceros coarctatus	0	0	0	0	0	0	0	0.6	0	0	0	0
Chaetoceros curvisetus	0	5.3	0	0	0	0	0.82	72.6	12.8	9.35	0	26
Chaetoceros didymus	0	0	0	0	0	0	0	0	0	0.46	0	0
Chaetoceros diversus	0	1.8	0	0	0	0	3.3	0	0	0	0	0
Chaetoceros eibenii	0	0	0	0	0	0	7.4	8.2	61.6	0	0	0
Chaetoceros laciniosus	0	0	0	0	0	0	0	0	0	4.6	0	0
Chaetoceros lorenzianus	0	0	0	0	0	0	0	0	0	3.27	0	12.4
Chaetoceros socialis	0	0	0	0	0	0		0.6	0	0	0	0
Chaetoceros spp	0.67	15.8	0	0	0	34.6	0	0	0	0	0	0
Chaetoceros teres	0	0	0	0	0	0	0	0	0	0.46	0	0
Chaetoceros wighamii	0	1.8	0	0	0	0	0.82	0	0	0	0	0
Family: Biddulphieae												
Eucampia zodiacus	0	0	0	0	0	2.1	0	0	0		0.38	0
Streptotheca indica	0	0	0	0	0	0	0	0	0	0.46	0	0
Streptotheca thiamensis	0	0	0	0	0	0	0	0.6	0	1.4	0	0
Climacodium fraunfeldianum	0	0	0	0	0	0	0.82	0	0	0.46	0	0
Triceratium favus	14.8	5.3	1.8	28.23	12.2	5.4	4.13	0	1.7	0.46	2.3	0
Ditylum sol	0	0	0	0	0	2.7	17.36	0.6	0	0.9	0	0
Bellarochea malleus	0	1.8	0	0	0	0	2.48	0.6	1.7	0	0	0
Biddulphia mobiliensis	1.3	1.8	1.8	4.8	0	0	6.6	0.6	1.7	1.86	2.3	0.47
Biddulphia obtusa	0	3.6	0	0.8	0	0	0	0	0	0	0.38	0
Biddulphia pulchellum	0	0	0	0	0	0	0	0	8.2	0.46	0	0
Biddulphia sinensis	0	5.3	0	0	0	2.7	0.82	0.6	0	0	0.38	0.47
Biddulphia tuomeyi	0	0	0	0	0	0	0	0	0	0	0.38	0
Biddulphia heteroceros	0.67	0	0	0	0	0	0	0	0	0	0	0
Family: Hemiaulineae												
Hemiaulus sinensis	0	0	0	0	0	0	0	0	0	0.46	0	0
Order: Pennales			**Sub order: Araphidineae**									
Family: Fragilariodeae												
Climacosphenia elongata	0	0	5.4	0	0	0	0	0	0	0	0	0
Climacosphenia moniligera	0	0	0	0.8	0	0	0	0	0	0	0.38	0
Rhabdonema mirificum	0	0	1.8	0.8	0	0	0.82	0	0	0	0	0
Asterionella japonica				0	0	0	0	0	0	4.6	0	0
Fragilaria oceanica	0.67	1.8	0	0	4.8	0	0	0	0	0.46	76.8	0
Thalassionema nitzschioides	0	0	0	0	0	0	9.09	0	0	37.4	0	0
Thalassiothrix fraunfeldii	0	0	0	21.8	0	0	0	0	0	0	0.38	0
Thalassiothrix longissima	31.5	0	0	0	0	0	0	0	0	0	0	0

table contd….

Species	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Sub order: Biraphideae												
Family: Naviculoideae												
Pleurosigma elongatum	0	0	1.8	0	0	0	0	0	0	0	0.38	0
Pleurosigma normani	0	0	0	0	0	0	2.48	0	0	0.46	0	0
Pleurosigma aestuarii	1.3	0	0	0	0	0	0	0	0	0	0	0
Gyrosigma balticum	1.3	0	0	0	0	0	0	0	0	0	0	0
Navicula forcipata	0.67	0	0	0	0	0	0	0	0	0	0	0
Amphiprora gigantea	0	0	0	0.8	0	0	0	0	0	0	0	0
Amphora lineatus	0	0	0	0	0	0	0	0	0	0.46	0	0
Family: Nitzschiaceae			**Sub family : Nitzschioideae**									
Nitzschia pungens	0	0	0	0	0	0	0	0	0	0	0	4.6
Nitzschia seriata	0	0	0	0.8		0	5.8	1.2		7	0	0
Nitzscia sigma	0	0	0	0	0	0	0	0	0	0.9	0	0
Nitzschia panduriformes	1.3	0	0	0	0	0	0	0	0	0	0	0
Nitzschia lanceolata	0	1.8	0	0	0	0	0	0	0	0	0	0
Division : PYRROPHYTA												
Class : Dinophyceae												
Sub Class:Dinokontae												
Order : Peridinales												
Family: Ceratiaceae												
Ceratium breve	0	1.8	1.8	0	0	0	0	0	0	0	0	0.47
Ceratium conicoides	0	0	0	0	0	2.1	0	0	0	0	0	0
Ceratium furca	0	0	3.6	0.8	5.2	0	0	0	0	0	0	0
Ceratium fusus	0.67	0	0	0	0	2.1	0	0	0	0	0	0
Ceratium lunula	0	0	1.8	0	0	0	0	0	0	0	0	0
Ceratium macroceros	0	0	1.8	0.8	0	0	0	0	0	0	0	0
Ceratium trichoceros	0	0	1.8	0	0	0	0.82	0	0	0	0	0.47
Ceratium massiliense	0	0	0	0	0	0	0	0	0	0	0	0.47
Ceratium tripos	0.67	0	1.8	0.8	0	0	0	0	0	0	0	0.47
Ceratium humile	0.67	0	0	0	0	0	0	0	0	0	0	0
Family: Peridiniaceae												
Peridiium sp	0	1.8	0	0	6.4	2.1	0	0	0	0	0	0.47
Peridinium claudicans	0	0	0	0	0	5.4	0	0	0	0	0	0
Peridinium conicoides	0	0	0	0	0	0	0	0.6	0	0.46	0	0
Peridinium depressum	0	0	0	0.8	0	0	0	0	0	0	0	0
Peridinium divergens	2.7	0	0	0.8	0	2.1	0	0	0	0	0	0
Peridinium elegans	0	0	0	0	0	0	0.82	0	0	0	0	0
Peridinium granii	1.3	0	0	0	0	0	0	0	0	0	0	0
Peridinium grande	0	0	0	0.8	0	0	0	0	0	0	0	0
Peridinium leonis	0	0	0	0.8	0	0	0	0	0	0	0	0
Peridinium pentagonum	0.67	0	0	0	0	0	0	0	0	0	0	0
Peridinium oceanicum	0	0	3.6	0	0	0	0	0	0	0	0	0
Peridinium murrayi	1.3	0	0	0.8	0	0	0	0	0	0	0	0
Peridinium tristylum	0	0	0	0.8	0	0	0	0	0	0	0	0
Order : Gonyalaucales												
Family: Pyrophacaceae												
Pyrophacus horologium	0	0	1.8	0.8	0	0	1.65	0	0	0	0	0
Order : Dinophysiales												
Family : Dinophysiaceae												
Dinophysis caudata	9.4	0	23.2	3.4	8.8	2.1	0	0	0	0	0	2.4
Dinophysis miles	0	0	5.4	0.8	0	0	0	0	0	0	0	0.47
Ornithocercus sp	0.67	0	0	0	0	0	0	0	0	0	0	0
Ornithocercus magnificus	0	0	0	0.8	5.2	0	0	0	0	0	0	0
Sub Class :Desmokontae												
Order : Prorocentrales												
Family : Prorocentraceae												
Prorocentrum micans	0.67	0	0	0.8	0	0	0	0	0	0	0	0
Division: CYANOPHYTA												
Class: Cyanophyceae												
Order: Oscillatoriales												
Family: Oscillatoriaceae												
Trichodesmium erythraeum	0	0	5.4	0.8	0	0	4.13	0	0	0	0	0
Blue green algae	0	0	0	0	0	0	5.8	0	0	0	0	0
Others	3.63	9.8	3.3	2.83	5.2	2.3	4.25	0.2	0.1	1.74	0.44	0.04

Table. 1.7b Results of the qualitative analysis of phytoplankton at Vizhinjam sea from Oct 02 to Aug 03.

	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug
Class: Bacillariophyta											
Order: Centrales			**Sub order: Discoideae**								
			Family: Coscinodisceae								
Melosira sulcata	0	0	0	0	0	0	0	0.64	0	6.6	1.6
Stephanopyxis palmeriana	0	0	0	0.5	0	1.15	0	0	0	0	0
Stepahanopyxis turris	0	0	0.77	0	0	0	0	0	0	0	0
Skeletonema costatum	0	0	0	38.2	0	0	1.15	4.5	14.3	0	0
Thallassiosira subtilis	0	0	0	0	0	0	0	0.64	4.8	1.6	0
Coscinodiscus asteromphalus	0	0	0	0	0	0	0	0	0.95	0	0
Coscinodiscus centralis	0	0	0	0	0	0	0	0	0	1.6	0
Coscinodiscus excentricus	1.69	0	0	0	0	2.3	0	0	0.95	0	0
Coscinodiscus gigas	0	0	0	0	0	0	0	0	0.95	0	0
Coscinodiscus oculus iridis	0	0	0	5.1	0	0	0	0	0	0	0
Coscinodiscus sp	0	0	0	0	0	1.15	0	0	0	0	0
Coscinodiscus sublineatus	0	0	0	0.5	0	0	0	0	0	14.8	0
Planktionella sol	0	0	0	0	0	1.2	0	0.64	0	0	0
			Family: Eupodisceae								
Actinoptychus splendens	0.42	0	0.77	0	0	0	0	0.43	0.95	0	0
Actinoptychus undulatus	0	0	0	1	4.2	2.3	0	0	0	0	0
			Sub order: Solenoideae								
			Family: Solenieae								
Lauderia annulata	0.42	0.94	0	0	0	0	0	5.6	0	0	
Schroederella delicatula	0	0	0	0	0	0	1.15	6	0	0	0
Leptocylindrus danicus	0	0	0	0.5	0	1.15	0	0.64	0	0	0
Rhizosolenia alata	0	1.9	0.77	0.5	0.85	11.5	1.36	0.64	1.9	1.6	0
Rhizosolenia castracanei				0.5	0	0	0	0	0	0	0
Rhizosolenia crassispina	0	0.94	0	0	0.85	0	0	0	0	0	1.6
Rhizosolenia imbricata				0	0	3.4	1.15	0	0.95	0	0
Rhizosolenia robusta				0	0	1.15	1.36	0	0.95	0	0
Rhizosolenia styliformis	0.84	0.94	1.5	0	0	17.2	0	0	0	0	0
Rhizosolenia stolteforthii	0.42	0	0	0	0	0	0	0	0	0	0
Sub order: Biddulphioideae											
			Family:Chaetocereae								
Bacteriastrum delicatulum	0	0	0	0	0.85	0	0	0.64	0	0	0
Bacteriastrum elongatum	0	0	0	0.5	0	0	0	0	0	0	0
Bacteriastrum varians	0	0	0	0	0	0	0	0.64	0.95	0	0
Bacteriastrum elegans	0	0.94	0.77	0	0	0	0	0	0	0	0
Bacteriastrum sp	0.42	0	0	0	0	0	0	0	0	0	0
Chaetoceros affinis	0	0	0.77	0	0.85	0	0	6.5	0	0	0
Chaetoceros coarctatus	0	0	0	0	0.85	3.4	1.15	0	0	0	0
Chaetoceros concavicornis	0	0	0	0	0	0	0	0	0.95	0	0
Chaetoceros curvisietus	38.1	4.7	38.5	22.9	0	0	8.6	46.5	9.5	3.3	25.8
Chaetoceros decipiens	0	0	0	0	0	0	0	0	0.95	0	25.8
Chaetoceros diversus	0	1.9	0	0	0.85	1.15	0	0	0	0	0
Chaetoceros indicus	0	0	0	0	0	0	2.3	0	0	0	0
Chaetoceros lorenzianus	19.06	0	0.77	2	0	0	2.3	1.3	1.9	1.6	1.6
Chaetoceros peruvianus	0	0	0	0	0	0	1.15	0	0	0	0
Chaetoceros socialis	0	0	0	0	0	0	1.15	0	0	0	0
Chaetoceros teres	0	0	0	0	0	0	0	0	0	1.6	0
Chaetoceros wighamii	0	0	0	0	0.85	0	0	4.5	0	0	0
			Family: Biddulphieae								
Eucampia cornuta	0	0	0	0	0	4.6	0	0	0	0	0
Eucampia zoodiacus	0	0	0	0	0	1.15	0	0	0	0	0
Streptotheca thiamensis	0.42	0	0.77	0	0	0	0	0	0	0	0
Triceratium favus	0.42	0.94	3.8	2.6	16.9	0	1.15	0	0.95	4.9	0
Triceratium reticulum	0	0	0	0	0	0	0	0	0	4.9	0
Bellarochea malleus	0	0	0.77	0	2.5	1.2	1.5	0	0	8.2	0
Ditylum sol	0.42	14.2	3.8	0	0	0	39.7	0.64	1.9	0	0
Biddulphia mobilensis	0	0.94	10	1.5	2.5	0	1.5	0	0.95	1.6	0
Biddulphia obtusa	0	0	0	0	0	0	0	0	0	1.6	1.6
Biddulphia pulchellum	0	0	0	0	0.85	0	0	0.64	0	0	0
Biddulphia sinensis	0.42	0.94	0	0	0	1.2	1.15	0.64	0.95	3.3	1.6
Biddulphia tuomeyi	0	0	0	0	0	0	1.15	0	0	0	0

table contd….

	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug
Family: Euodieae											
Hemidiscus hardmanianus	1.27	2.8	0	0	0	0	0	0	0	0	0
Order: Pennales			**Sub order: Araphidineae**								
Family: Fragilariodeae											
Climacosphenia moniligera	0	0	0.77	0	0	0	0	0	0	0	0
Rhabdonema mirificum	0	0	0	0	0.85			0	0	0	0
Grammatophora undulata	0	0	0.77	0.5	0	0	0	0	0	0	0
Asterionella japonica	0	0	4.6	0	0	0	1.36	0.64	0.95	1.6	3
Fragilaria oceanica	0	0.94	0.77	0	11	2.3	12.2	11.6	0.95	14.8	11.2
Thalassionema nitzschiodes	1.69	23.4	0	0	0	0	0	0	0	4.9	8
Thalassiothrix fraunfeldii	0.84	23.6	7.7	0	2.5	11.5	4.6	0.64	0	0	0
Sub order: Biraphideae											
Family: Naviculoideae											
Pleurosigma elongatum	0	0	0	0.5	0	0	0	0	0	0	0
Pleurosigma normani	0	0	1.5	0	1.7	1.15	1.15	0	0	0	0
Gyrosigma balticum	0	0	0.77	0	0	0	0	0	0	0	0
Navicula spp	0	0	0	0.5	0	0	0	0	0	0	0
Diploneis robusta	0	0	0	0	0	1.15	0	0	0	0	0
Mastoglia exilis	0	0	0	0	0.85	0	0	0	0	0	0
Mastoglia minuta	0	0	0.77	0	0	1.15	0	0	0	0	0
Amphiprora gigantea	0	0	0	0	0	0	0	0	0.95	0	0
Family: Nitzschiaceae											
Nitzschia lanceolata	0	0	0	0	0	0	3.8	0.64	0	0	0
Nitzschia longissima	0	0	0	0.5	0	0	0	0	0.95	0	0
Nitzschia pungens	23.3	0	2.3	0		0	0	0	43	3.3	1.6
Nitzschia seriata	0	0	0	1	1.7	2.3	0	2.6	0	0	0
Nitzschia sigma	0	0	0	0	5.9	3.4	0	0	0	0	0
Bacillaria paradoxa	0	0	0	0	0.85	0	0	0	0	0	0
Division : PYRROPHYTA											
Class : Dinophyceae											
Sub Class:Dinokontae											
Order : Peridinales											
Family: Ceratiaceae											
Ceratium breve	0	0.94	0.77	0	1.7	1.15	0	0	0	0	0
Ceratium carriense	0	0	0	0	0.85	0	0	0	0	0	0
Ceratium contortum	0	0	0	0.5	0	0	0	0	0	0	0
Ceratium furca	0	0	0	0	0.85	1.15	0	0	0.95	0	0
Ceratium lunula	0	0	0.77	0	0	0	0	0	0	0	0
Ceratium macroceros	0	0	0	0	0.85	0	0	0.64	0	0	0
Family: Peridiniaceae											
Peridinium spp	2.96	0.94	0.77	0	2.5	1.15	0.75		0	4.9	0
Peridiniopsis sps	0	0	0	0.5	0	0	0	0	0	0	0
Peridinium claudicans	0	0.94	0	0	2.5	0	0	0	0	0	0
Peridinium oceanicum				0	0	0	0	0	0	3.3	0
Family : Ceratocoryaceae											
Ceratocorrys horrida	0	0	0.77	0	0	0	0	0	0	0	0
Order : Gonyalaucales											
Family: Pyrophacaceae											
Pyrophacus horologium	0.42	0.94	0	0.5	0	0	0.75	0	0	0	0
Order : Dinophysiales											
Family : Dinophysiaceae											
Dinophysis caudata	0.42	11.3	0	0	7.6	5.7	0	0.64	0	1.6	0
Dinophysis miles	0.42	0	0	0	0	0	0	0	0	0	0
Ornithocercus magnificus	0.42	0.94	0	0	0.85	0	0	0	0	0	0
Order: Noctilucales											
Family :Noctilucaceae											
Noctiluca scintillans	0	0	0	0	0	0	0	0	0	0	16
Sub Class :Desmokontae											
Order : Prorocentrales											
Family : Prorocentraceae											
Prorocentrum micans	0	0	0	0	0.85	0	0	0	0	0	0
Division: CYANOPHYTA											
Class: Cyanophyceae											
Order: Oscillatoriales											
Family: Oscillatoriaceae											
Trichodesmium erythraeum	0	0	0	15.3	18.6	12.6	0	0	0	0	0

Table. 1.8a. Results of the qualitative analysis of phytoplankton from Oct 01 to Sept 02 at Vizhinjam bay

Species	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Class: Bacillariophyta												
Order: Centrales	**Sub order: Discoideae**											
Family: Coscinodisceae												
Melosira sulcata	0	2.2	0	0	0	0	0	4.2	3.38	4.4	0	0
Stephanopyxis palmerianna	0	0	0	0	0	0	0	0	0	0	0.5	0.57
Coscinodiscus asteromphalus	0	0	0	0	0	0	0	0	0	0	2.3	0
Coscinodiscus sub-lineatus	2	0	3.84	0	0	0	10.4	0	19.7	36.9	2.3	38.8
Coscinodiscus conicoides	0	11.1	0	0	0	0	0	0	0	0	0	0
Skeltonema costatum	0	0	0	0	0	0	0	0	0	4.4	0	0
Thallassiosira subtilis	0	0	0	0	36.2	8.6	2.08	0	0	0	0	0
Family: Eupodisceae												
Actinoptychus splendens	0	0	1.28	7.14	0	0	0	0	0	0	2.3	0
Actinoptychus undulatus	0	0	0	2.38	0	0	0	0	0.28	0	0	0
Sub order: Solenoideae												
Family: Solenieae												
Leptocylindrus danicus	0	2.2	0	0	1.4	1.12	0	0	0	0	0	0
Leptocylindrus minimus	0	0	1.28	0	0	0	0	0	0	0	0	0
Guinardia flaccida	0	0	0	0	0	0	0	0	0	0.08	0	0
Rhizosolenia alata	0.2	6.6	23	0	2.8	28.2	0	4.8	1.4	0	0	0.57
Rhizosolenia castracaneii	0	0	1.28	0	0	0	0	0	0	0	0	0
Rhizosolenia sp	0	0	0	0	12.8	0	0	0	0	0	0	0
Rhizosolenia styliformis	12.2	15.5	0	0	0	0	6.25	0	0.28	0	0	3.6
Rhizosolenia robusta	0	2.2	0	0	0	0	0	0	0	0	0	0
Rhizosolenia stolteforthii	0	8.8	0	0	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	0	6.6	1.28	0	0	0	0	0	0	0	0	0
Sub order: Biddulphioideae												
Family:Chaetocereae												
Bacteriastrum varians	0	0	0	0	0	0	0	0	1.4	0.44	0	0
Chaetoceros affinis	0	0	0	0	0	0	0	0	0.84	0.35	0	0
Chaetoceros curvisetus	0	6.6	0	0	0	0	0	88.6	0.28	0.08	0	24
Chaetoceros diversus	0	2.2	0	0	0	0	2.08	0	0	0	0	0
Chaetoceros eibinii	0	0	0	0	0	0	6.28	0	56.3	0.35	0	0
Chaetoceros lauderi	0	0	0	0	0	0	0	0	0	0.08	0	0
Chaetoceros lorenzianus	0	0	0	0	0	0	0	0	0	0	0	10
Chaetoceros spp	0.2	2.2	0	0	24.2	32.8	0	0	0	0	0	0
Chaetoceros wighamii	0	0	0	2.38	0	0	0	0	0	0	0	0
Family: Biddulphieae												
Eucampia zoodiacus	0	0	0	0	0	0	0	0	0	0	2.3	0
Streptotheca indica	0	0	0	0	0	0	0	0	0.28	0.08	0	0
Triceratium favus	6.1	2.2	3.84	42.8	0	0	10.4	0	0.84	0.26	4.1	0.57
Bellarochea malleus	0	0	0	0	0	0	2.08	0	0.28	0	0.8	0
Ditylum sol	0	0	0	0	0	0	16.6	0	0	0	0	0
Biddulphia mobilensis	6.1	4.4	2.56	4.76	0	0	0	2.4	0	0.3	1.7	0
Biddulphia obtusa	0	6.6	1.28	0	0	0	0	0	0	0	2.3	0
Biddulphia pulchellum	0	0	0	0	0	0	0	0	9.85	0.62	0	0
Biddulphia sinensis	0	2.2	0	0	0	0	0	0	0.28	0	0	0
Biddulphia heteroceros	0.2	0	0	0	0	0	0	0	0	0	0	0
Biddulphia tuomeyi	0	0	0	0	0	0	0	0	0	0	2.3	0
Family: Hemiaulineae												
Hemiaulus sinensis	0	2.2	0	0	0	0	2.08	0	0	0	0	0
Order: Pennales	**Sub order: Araphidineae**											
Family: Fragilariodeae												
Climacosphenia	0	0	1.28	0	0	0	0	0	0	0	2.3	0
Rhabdonema mirificum	0	2.2	1.28	7.14	0	0	0	0	0	0	0	0
Asterionella japonica	0	0	0	0	0	0	0	0	0.28	0.53	0	0
Fragilaria oceanica	0.2	0	0	0	0	0	0	0	0.28	6.69	72.6	0
Thalassionema nitzschioides				2.38	0	0	6.25	0	0.84	33.89	1.5	0
Thallassiothrix fraunfeldii	0	2.2	1.28	9.5	0	0	0	0	0	0	0	0
Thallassiothrix longissima	48.8	0	0	0	0	0	0	0	0	0	0	0
Sub order: Biraphideae												
Family: Naviculoideae												
Gyrosigma balticum	1.3	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma normanii	0	0	1.28	0	0	0	0	0	0	0.35	0	0
Pleurosigma aestuarii	1.3	0	0	0	0	0	0	0	0	0	0	0
Navicula forcipata	0.2	0	0	0	0	0	0	0	0	0	0	0

table contd....

Species	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept
Family: Nitzschiaceae												
Nitzschia pungens	0	0	0	0	0	0	0	0	0	0	0	18.4
Nitzschia seriata	0	0	0	0	0	0	0	0	2.25	4.4	0	0
Nitzscia sigma	0	0	1.28	0	0	0	0	0	0	0.08	0	0
Nitzschia panduriformes	1.3	0	0	0	0	0	0	0	0	0	0	0
Division : PYRROPHYTA												
Class : Dinophyceae												
Sub Class:Dinokontae												
Order : Peridinales												
Family: Ceratiaceae												
Ceratium breve	0.2	2.2	1.28	0	0	0	0	0	0	0	0	0.57
Ceratium conicoides	0	0	0	0	0	1.12	0	0	0	0	0	0
Ceratium dens	0	0	0	0	0	0	4.2	0	0	0	0	0
Ceratium furca	0	0	0	0	2.8	1.12	0	0	0	0	0	0
Ceratium horridum	0	0	0	0	1.4	1.12	0	0	0	0	0	0.57
Ceratium macroceros	0	0	0	0	1.4	1.12	2.08	0	0	0	0	0
Ceratium fusus	0.2	0	0	0	0	0	0	0	0	0	0	0
Ceratium sp	0	0	0	0	0	0	0	0	0	0	0	0.57
Ceratium hexacanthum	0	0	1.28	0	0	0	0	0	0	0	0	0
Ceratium declinatum	0	0	1.28	0	0	0	0	0	0	0	0	0
Ceratium massiliense	0	0	1.28	0	0	0	0	0	0	0	0	0
Ceratium pulchellum	0	0	1.28	0	0	0	0	0	0	0	0	0
Ceratium schmidtii	0	0	1.28	0	0	0	0	0	0	0	0	0
Ceratium tripos	0.2	0	0	0	0	0	0	0	0	0	0	0
Ceratium vultur	0	0	1.28	0	0	0	0	0	0	0	0	0
Family: Peridiniaceae												
Peridiium spp	3	0	0	0	0	0	0	0	0	0	2.3	0
Peridinium claudicans	0	0	0	0	1.4	0	0	0	0.56	0	0	0
Peridinium divergens	2.7	0	0	0	0	1.12	0	0	0	0	0	0
Peridinium murrayi	0	0	0	0	1.4	1.12	0	0	0	0	0	0
Peridinium oceanicum	0	2.2	5.13	0	1.4	1.12	0	0	0	0	0	0
Peridinium leonis	0	0	1.28	0	0	0	0	0	0	0	0	0
Peridinium pallidum	0	0	1.28	0	0	0	0	0	0	0	0	0
Peridinium subinerme	0	0	1.28	0	0	1.12	0	0	0	0	0	0
Peridinium elegans	0	0	1.28	0	0	0	0	0	0	0	0	0
Peridinium globulus	0	0	1.28	0	0	0	0	0	0	0	0	0
Peridinium murrayi	1.3	0	1.28	0	0	0	0	0	0	0	0	0
Peridinium pentagonum	0	0	1.28	0	0	0	0	0	0	0	0	0
Peridinium quarnerense	0	0	1.28	0	0	0	0	0	0	0	0	0
Order: Gonyalaucales												
Family: Pyrophacaceae												
Pyrophacus horologium	0	0	0	0	1.4	1.12	2.08	0	0	0	0	0
Order: Dinophysiales												
Family Amphisoleniaceae												
Amphisolenia bidentata	0	0	1.28	0	0	0	0	0	0	0	0	0
Family : Dinophysiaceae												
Dinophysis acuminata	0	0	0	0	0	0	0	0	0.28	0	0	0
Dinophysis caudata	12.2	6.6	12.8	7.14	10.4	12.6	0	0	0	0	0	0.57
Dinophysis miles	0	0	1.28	2.38	0	1.12	6.25	0	0	0	0	0.57
Diplopsalis lenticula	0	0	0	0	0	1.12	0	0	0	0	0	0
Ornithocercus	0	0	1.28	0	0	0	0	0	0	0	0	0
Ornithocercus magnificus	0	0	0	2.38	0	0	0	0	0	0	0	0.57
Sub Class :Desmokontae												
Order : Prorocentrales												
Family : Prorocentraceae												
Prorocentrum micans	0	0	1.28	0	0	4.3	0	0	0	0	0	0
Division: CYANOPHYTA												
Class: Cyanophyceae												
Order: Oscillatoriales												
Family: Oscillatoriaceae												
Trichodesmium spp	0	0	0	0	0	0	20.83	0	0	0	0	0
Others	0.1	0.8	11.7	0.12	1	0.06	0.06	0	0.12	5.72	0.4	0.07

Table.1.8b.Results of the qualitative analysis of phytoplankton at Vizhinjam bay from October 2002 to August 2003.

Species	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug
Class: Bacillariophyta											
Order: Centrales						**Sub order: Discoideae**					
				Family: Coscinodisceae							
Melosira sulcata	0	0	0	1.2	0	0	0	2.7	0	10.8	2.6
Stephanopyxis palmeriana	3.8	0	0.86	1.2	0	0	0	0	0	0	0
Coscinodidcus granii	0	0	0	0	0	0	0	0	0.7	0	0
Coscinodiscus oculus- iridis	0	0	0	4.8	0	0	0	0	0	0	0
Coscinodiscus perforatus	0	0	0	0	0	0	1.07	0	0	0	0
Coscinodiscus sublineatus	0	0	0	0	0	0	0	4.8	0	22.6	16
Coscinodiscus asteromphalus	0	0	0.86	0	0	0	0	0	0	0	0
Skeletonema costatum	0	0	0.86	18	6.8	0	0	1.1	8	0	0
Thalassiosira coramandeliana	0	0	0	0	0	0	0	1.6	0	0	0
Thalassiosira decipiens	0	0	0	3.6	0	0	0	0	0	0	0
Thalassiosira subtilis	0	0	0.86	0	0	0	0	0	0	1.6	0
Planktionella sol	0	0	0	1.2	0	0	1.07	0	0	1.6	0
				Family: Eupodisceae							
Actinoptychus splendens	0	0	0	3.6	0	0	1.07	0	0	0	0.66
				Sub order: Solenoideae							
				Family: Solenieae							
Lauderia annulata	0	0.54	0	1.2	1.5	1.12	0	0	0	0	0
Leptocylindrus danicus	0	0	0	0	0	1.12	1.07	4.9	0	0	0
Guinardia flaccida	0	0	0	1.2	0	0	0	0	0	0	0
Rhizosolenia alata	0	0.54	8.7	0	0	11.5	1.07	0	4	1.6	0
Rhizosolenia berganii	0	0.54	0	0	0	1.12		0	0	0	0
Rhizosolenia castracaneii	0	0.54	1.74	1.2	0	0	0	0	0	0	0
Rhizosolenia crassispina	0	0	0	0	1.35	0	0	0	0	0	0.66
Rhizosolenia cylindricus	0	0	0	0	0	0	0	0	0	0	0.66
Rhizosolenia hebetata	0	0	0.86	0	0	0	0	0	0	0	0
Rhizosolenia imbricata	0	0	0	0	0	0	0	0	0	0	1.3
Rhizosolenia stolteforthii	0	0	0	0	0	1.17	0	1.1	0	0	0
Rhizosolenia styliformis	0	8.1	0	3.6	1.35	22.47	0		1.3	0	0.66
Rhizosolenia setigera	0	0	7	0	0	0	0	0	0	0	0
Sub order: Biddulphioideae											
				Family:Chaetocereae							
Bacteriastrum delicatulum	0	0	0	1.2	0	0	0	0	0	0	0
Bacteriastrum varians	0	0	0	1.2	0	1.12	2.2		0.7	1.6	0
Chaetoceros affinis	0	0	0.86	0	0	0	0	3.7	0	0	0
Chaetoceros concavicornis	0	0	0	0	0	0	0	0	0	0	0.66
Chaetoceros curvisetus	45.8	1.6	1.7	6	0	1.12	1.07	36.2	16.4	4.5	4.6
Chaetoceros decipens	0	0	0	0	0	0	0	4.3	6.6	0	4.6
Chaetoceros diversus	0	4.3	0	0	0	1.12	0	0	0	0	1.3
Chaetoceros eibinii	0	0	0	1.2	0	0	0	0	0	0	0
Chaetoceros indicus	0	0	0	0	0	0	1.07	0	0	0	0
Chaetoceros lorenzianus	11.5	0	0	0	0	0	0	0	0	1.6	0.66
Chaetoceros socialis	0	0	0	0	0	0	0	0	0	0	0.66
Chaetoceros spp	0	0	0	0	2.7	0	3.2	0	0	0	0
Chaetoceros excentricus	7	0	0	0	0	0	0	0	0	0	0
Chaetoceros peruvianus	0	1.6	0	0	0	0	0	0	0	0	0
Chaetoceros wighamii	0	0	0	0	1.35	0	0	1	0	0	0
				Family: Biddulphieae							
Eucampia zoodiacus	0	0.54	0.86	1.2	0	16.8	0	0	0	0	0
Streptotheca thiamensis	0	0	0	0	0	0	0	1.1	0	0	0.66
Triceratium favus	0.76	0.54	8.7	6	9.5	9.2	1.07	0	0.7	3.6	0.66
Triceratium reticulum	0	0	0.86	0	0	0	0	0	0	3.6	0
Bellarochea malleus	0.76	0	0	1.2	1.35	0	5.4	0	0.7	4.5	0.66
Ditylum sol	0.76	2.2	3	0	0	0	48.4	1.6	2	0	0
Biddulphia mobilensis	0.76	0.54	4.3	1.2	1.35	1.12	1.07	0	0.7	1.6	2.6
Biddulphia obtusa	0	0	0	0	0	0	0	0	0	0	1.3
Biddulphia pulchellum	0	0	0	1.2	1.35	0	0	0	0	0	0
Biddulphia rhombus	0	0	0.86	0	0	0	0	0	0	0	0
Biddulphia sinensis	0.76	0	3	1.2	0	1.12	1.07	2.7	0.7	1.6	1.3
Order: Pennales			**Sub order: Araphidineae**								
				Family: Fragilariodeae							
Grammatophora undulata	0	0.54	0	0	0	1.12	0	0	0	0	0

table contd....

Species	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug
Climacosphenia moniligera	0	0.54	0.86	0		0	0	0	0.7	0	0
Asterionella japonica	0	0	0.86	0	0	0	1.07	2.7	1.3	1.6	2.6
Fragilaria oceanica	0	0	8.7	3.6	4	1.12	10.8	9.6	2	10.6	17
Thalassionema nitzschiodes	0.76	28	0.86	0	0	1.12	0	0	0	4.5	11.8
Thalassiothrix frauenfeldii	2.3	31.2	17.4	4.8	6.8	3.4	10.8	2.7	0.7	1.6	1.9
Thalassiothrix longissima	0	5.3	0	0	0	0	0	0	0	0	0
Sub order: Biraphideae											
Family: Naviculoideae											
Amphiprora gigantea	0	0	0	0	0	0	0	0	2.6	0	0.66
Pleurosigma elongatum	0	0	2	0	0	0	0	0	0	0	1.3
Pleurosigma normanii	0	0	0	0	4	0	1.07	1	0	0	0
Gyrosigma balticum	0	0	1.7	0	0	0	0	0	0	0	0
Diploneis smithii	0	0	0	1.2	0	0	0	0	0	0	0
Family: Nitzschiaceae											
Nitzschia longissima	0	0	0	0	0	0	0	2.7	0	0	0
Nitzschia pungens	19	5.3	0	0	0	0	0	10	48	0	9.8
Nitzschia seriata	0	0	0	0	6.8	0	1.07	0	0	0	0
Nitzschia lanceolata	0	1.6	0	0	0	0	0	0	0	0	0
Nitzschia sigma	0	0	0.86	1.5	6.8	0	0	0	0	0	0
Division : PYRROPHYTA											
Class : Dinophyceae											
Sub Class:Dinokontae											
Order : Peridinales	**Family: Ceratiaceae**										
Ceratium dens	1.5	0	0	1.2	0	0	0	0	0.7	0	0
Ceratium furca	0	0	0.86	3.6	1.35	1.12	0	0	0.7	0	0
Ceratium macroceros	0	0	0	0	2.7	0	0	0	0	0	0
Ceratium massiliense	0	0	0	1.2	0	1.12	0	0	0	0	0
Ceratium schmidtii	0	0	0	1.2		0	0	0	0	0	0
Ceratium trichoceros	0	0	0	0	1.35	0	0	0	0	0	0
Ceratium tripos	0	0	0	1.2		0	0	0	0	0	0
Ceratium horridum	0	0	2.6	0	0	0	0	0	0	0	0
Family: Peridiniaceae											
Peridinium spp	3.8	1	0	0	4	0	1.1	4.2	0.7	4.5	0.66
Peridinium claudicans	0	1	0	0	13.5	1.12	1.1	0	0	0	0
Peridinium conicoides	0	0	0	2.4	0	0	0	0	0	0	0
Peridinium elegans	0	0	0	1.2	0	0	0	0	0	0	0
Peridinium murrayi	0	0	0	1.2	0	0	0	0	0	0	0
Peridinium pentagonum	0	0	0	0	0	0	1.1	0	0	0	0.66
Peridinium steinii	0	0	0	1.2	0	0	0	0	0	0	0
Peridinium oceanicum	0	0	0.86	0	0	0	0	0	0	0	0
Peridinium leonis	0	0	0.86	0	0	0	0	0	0	0	0
Peridinium pallidum	0	0	1.74	0	0	0	0	0	0	0	0
Mesodinium rubrum	0	0.54	0	0	0	0	0	0	0	0	0
Order: Gonyalaucales											
Family: Pyrophacaceae											
Pyrophacus horologium	0	0	0.86	2.4	1.35	0	0	0	0	0	0
Order: Dinophysiales											
Family Amphisoleniaceae											
Amphisolenia bidentata	0	0	0.86	0	0	0	0	0	0	0	0
Family : Dinophysiaceae											
Dinophysis caudata	0	1.6	0	1.2	10.8	9.2	1.07	0	0	4.5	0
Dinophysis miles	0	0	2.6	0	0	0	0	0	0	0	0
Ornithocercus magnificus	0	0	0.86		0	0	0	0	0	0	0.66
Order: Gymnodinales											
Family:Noctilucaceae											
Noctiluca scintillans	0	0	0	0	0	0	0	0	0	0	11
Sub class:Desmokontae											
Order: Prorocentrales											
Family: Prorocentraceae											
Prorocentrum micans	0	0	0	1.2	0	0	1.1	0	0	0	0
Prorocentraceae	0	0	0	1.2	0	0	1.1	0	0	0	0
Class: Cyanophyceae											
Order: Oscillatoriales											
Family: Oscillatoriaceae											
Trichodesmium spp	0	0	0	0	0	9.2	0	0	0	0	0
Others	0.74	1.8	8.78	6.1	6.6	0.26	0	0.3	0.1	11.9	0

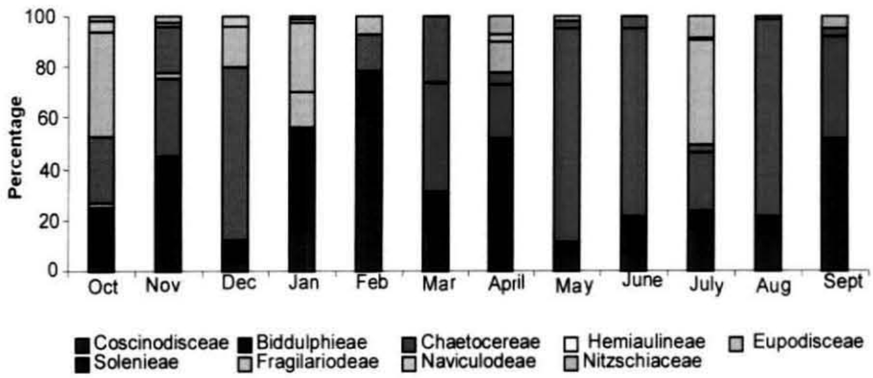


Fig.1.10a. **Composition (%)** of families of diatoms at Vizhinjam sea in the first year

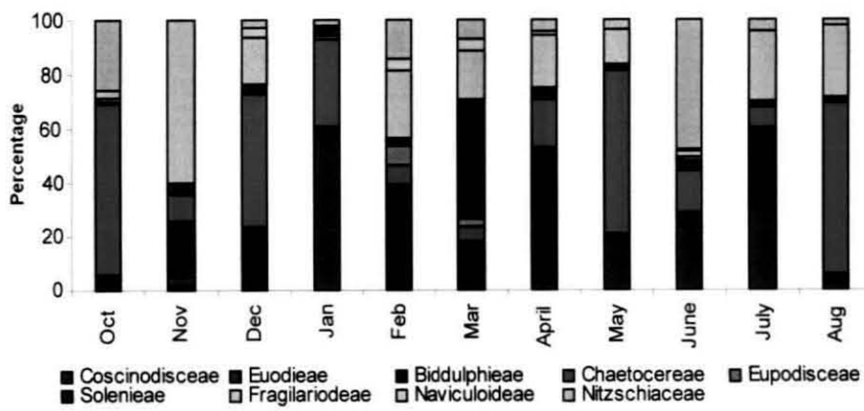


Fig.1.10b. **Composition (%)** of families of diatoms at Vizhinjam sea in the second year

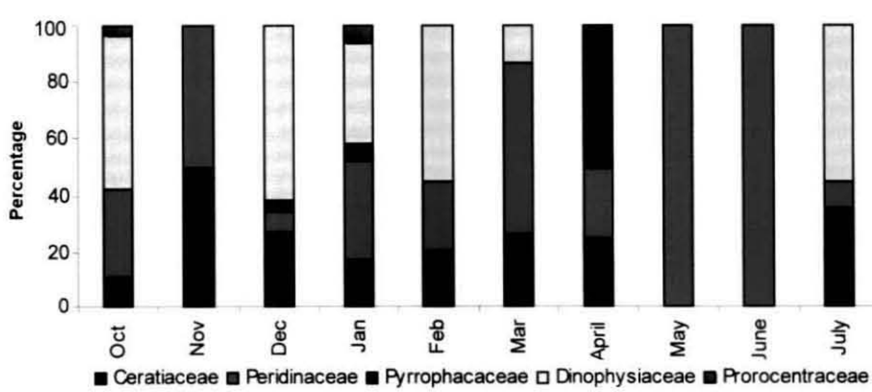


Fig.1.11a. **Composition (%)** of families of dinoflagellates at Vizhinjam sea in the first year

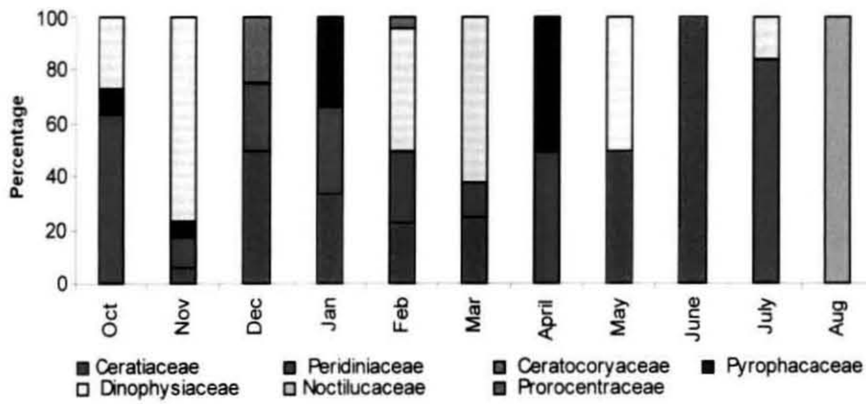


Fig. 1.11b **Composition(%)** of families of dinoflagellates at Vizhinjam sea in the second year

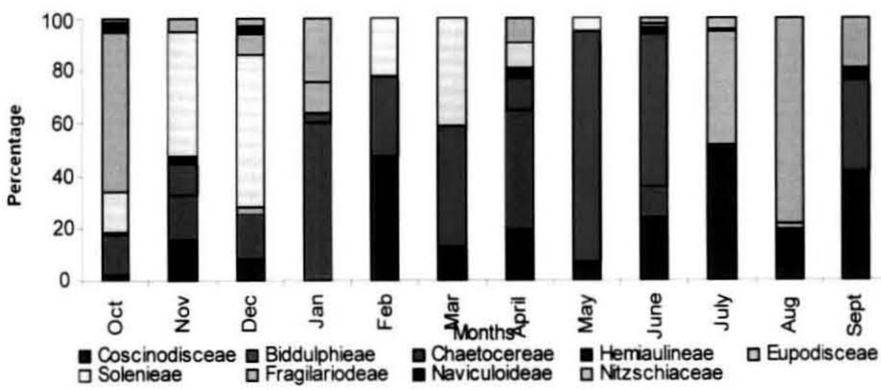


Fig. 1.12a **Composition (%)** of families of diatoms at Vizhinjam bay in the first year

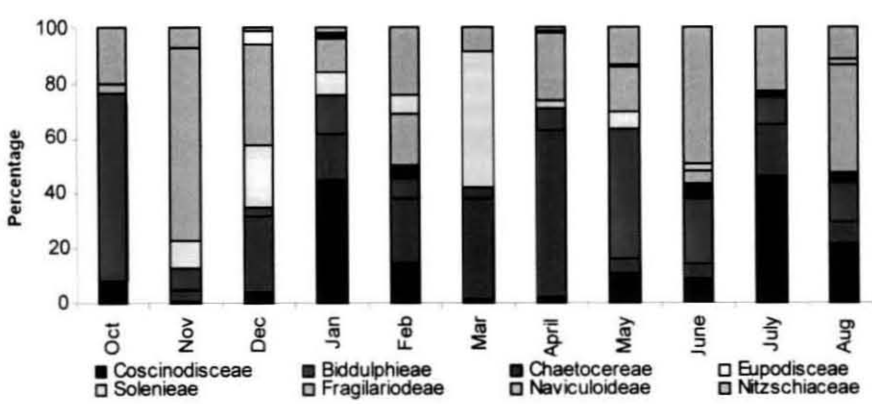


Fig. 1.12b **Composition (%)** of families of diatoms at Vizhinjam bay in the first year

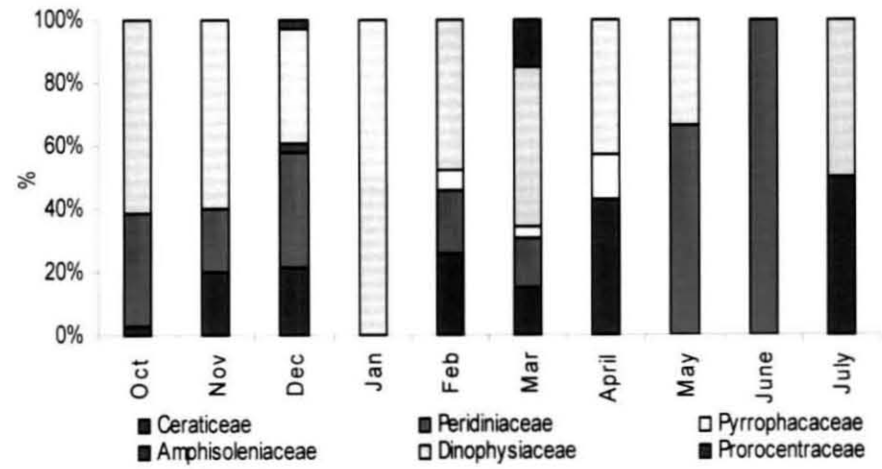


Fig. 1.13a. % Composition of families of dinoflagellates at Vizhinjam bay in the first year

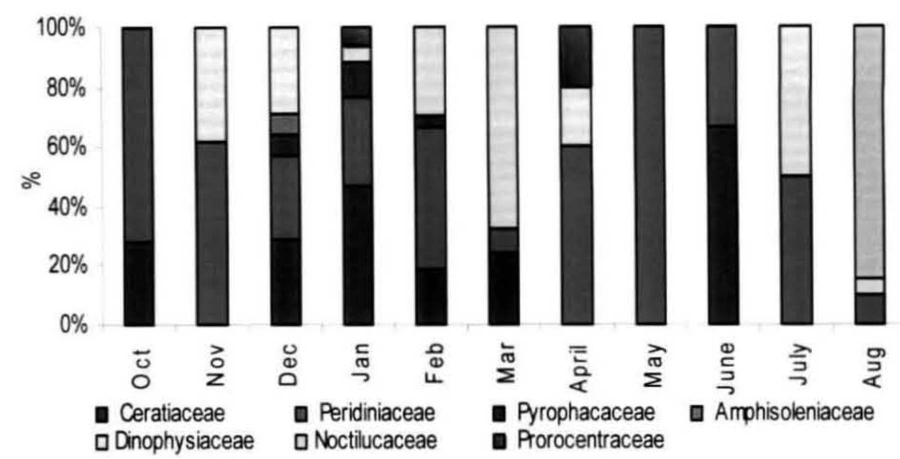


Fig. 1.13b. % composition of families of dinoflagellates at Vizhinjam bay in the second year

There were no representatives from this class in the months of August, October, December 2002 and in January 2003. *Trichodesmium sp* was present in higher frequency and cell numbers varied from 750 cells l^{-1} in May 2003 to 2500 cells l^{-1} in February 2003. It was detected in the samples from the stations during the period from December to March and in May.

In the bay, phytoplankton density showed a major peak in October 2002 with a density of 89 x 10^5 cells l^{-1} and minor peaks in the monsoon months of August 2002 and 2003 with a density of 6,34,000 cells l^{-1} and 4,95,725 cells l^{-1} respectively. After a major peak in October, it reduced to a minimum of 836 cells l^{-1} in November. In June 2003 also, a low density of 3106 cells l^{-1} was noticed. The minor peak in August 2002 was due to the bloom of *Fragilaria oceanica* at a density of 4,98,000 cells l^{-1} and in August 2003 by *Chaetoceros curvisetus* at a density of 84 x 10^5 cells l^{-1}. Bacillariophyceae was dominant both in terms of species and abundance. The concentration of diatom varied from as low as 574 cells l^{-1} in November 2002 to highest of 88,84,000 cells l^{-1} in October 2002. Dinoflagellates were lesser in abundance with cell numbers below a few thousands cells l^{-1}, except in October 2002 and August 2003 when it reached 22,800 cells l^{-1} and 55,000 cells l^{-1} respectively. Maximum density of dinoflagellates was in August 2003 when the toxic dinoflagellate *Noctiluca scintillans* was present. Dinoflagellates were absent in monthly samples of April and May. Cyanophyceae were present at a lower concentration of 2240 and 971 cells l^{-1} in March and June respectively.

The results of the quantitative analysis of phytoplankton at Vizhinjam sea and bay is presented in Table.1.9.a and b and the variation in phytoplankton density is presented in Fig.1.4 b and c.

C. DIVERSITY INDICES

In the sea, the species numbers were the highest in July with 29 species in the first year and in February with 30 species the second year. The species were the lowest in June with 9 species and in August in the second year with 12 species. In the bay species numbers were highest of 35 in December in the first year and 38 in January in the second year. Lowest species number of 4 was recorded in May the first year coinciding with the bloom of *Chaetoceros curvisetus*. Lowest species number of 14 was recorded in October in the second year. In both the sites species numbers were highest when the maximum number of dinoflagellates were also recorded.

At Vizhinjam sea the highest diversity of 2.75 was noted in April and 2.84 in March in the second year. Lowest diversity was noticed in the month of August with a value of 0.963 and in the second year in October with a value of 1.72. The highest diversity at Vizhinjam bay was observed as 2.95 in December the first year and 3.24 in January the second year. These were also the months with the highest dinoflagellate diversity. Lowest was 0.48 in May the first year and 1.73 in October 2002 the second year. The variation in Shannon- Wiener's diversity at bay and sea is represented graphically in Fig. 1.14a and b.

Evenness values for both sea and bay stations were highest for the months of November and April 2002. It approached values near to one with 0.92 and 0.90 at bay and 0.9 and 0.86 at sea in these months. Lowest values were observed both at bay and sea for the month of May 02, 0.343 in bay and 0.413 at sea. The second year the evenness value never fell below 0.5. Lowest of this was 0.63 in June 2003 at bay and 0.56 in October 2002 at sea. The variation in evenness at bay and sea is represented graphically in Fig. 1.15. The results of the analysis of diversity and evenness indices for Vizhinjam sea and bay are presented in Table.1.10a and 1.10b.

D. MULTIVARIATE ANALYSIS OF THE PHYTOPLANKTON COMMUNITY STRUCTURE OF THE REGION

The cluster analysis for the first year in the bay grouped the months into four clusters at 25 % similarity. These were Cluster I which consisted of the month of May during which there was a bloom of the diatom *Chaetoceros curvisetus*, Cluster II which consisted of the pre-monsoon months of February and March, Cluster III which consisted of the post-monsoon months September, October, November, December and January within which October, November and December and January formed two tightly clustered groups, Cluster IV which consisted of the monsoon months June, July, August and the late pre-monsoon month of April.

The results of similarity percentage analysis showed that the similarity in species composition in Cluster II was contributed the maximum by the dinoflagellates *Dinophysis caudata* and the remaining 60 % by diatoms. In Cluster III, 60% of the similarity was contributed by dinoflagellates alone. The similarity in Cluster IV was contributed entirely by diatoms.

Table. 1.9a. Results of the quantitative analysis of phytoplankton at Vizhinjam sea from August 2002-August2003. (Density in cells l^{-1})

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug
Chaetoceros curvisetus	0	44200	7000000	0	32124	3233	0	0	980	20250	720	0	152000
Chaetoceros lorenzianus	0	20225		0	0	0	0	0	490	0	0		0
Chaetoceros affinis	0	0	120000	0	0	0	0	0	0	0	0	0	0
Chaetoceros decipiens	0	0	80000	0	0	0	0	0	0	0	0	0	152000
Chaetoceros indicus	0	0	0	0	0	0	0	0	490	0	0	0	0
Chaetoceros sp	0	0	0	0	0	0	0	0	0	750	0	0	0
Coscinodiscus sublineatus	56250	0	0	0	0	0	0	0	0	0	0	1285	0
Coscinodiscus spp	11250	82850	0	606	0	0	0	740	0	3750	0	0	0
Coscinidiscus oculus iridis	0	0	0	0	0	233	0	0	0	0	0	0	0
Coscinodiscus granii	0	0	0	0	48	0	0	0	0	0	0	0	0
Biddulphia mobilensis	12500	0	0	0	7343	63	0	0	82	0	0	214	0
Biddulphia tuomeyi	2500	0	0	0	0	0	0	0	0	0	0	0	0
Biddulphia sinensis	2500	0	0	0	0	0	0	0	82	0	0	0	12000
Biddulphia sp	0	0	0	0	0	0	0	0	0	0	0	142	0
Triceratium favus	12500	0	0	0	0	63	2850	0	0	0	0	0	0
Triceratium alterans	0	0	0	0	0	0	0	0	0	750	0	0	0
Leptocylindrus danicus	0	0	0	0	0	0	0	0	0	5250	0	0	0
Ditylum sol	0	0	0	0	3872	0	0	0	8450	0	0	0	0
Bellarochea malleus	0	0	0	0	0	0	0	0	82	0	0	0	0
Rhizosolenia styliformis	0	14600	0	0	48	566	0	2845	82	0	0	0	0
Rhizosolenia alata	0	0	0	0	0	0	285	1480	320	0	0	0	0
Rhizosolenia imbricata	0	0	0	0	0	0	0	740	0	0	0	0	0
Rhizosolenia sps	0	0	0	0	0	0	0	0	0	2250	0	0	0
Melosira sulcata	0	0	0	0	0	0	0	0	0	750	0	1071	0
Stephanopyxis palmerianna	1250	0	14000	0	0	0	0	0	0	0	0	0	0
Skeltonema costatum	0	0	0	0	0	4245	0	0	0	0	0	0	0
Actinoptychus undulatus	0	0	0	0	0	0	547	185	0	0	0	0	0
Amphora lineolata	0	0	0	0	0	0	0	0	0	0	0	357	0
Navicula spp	0	0	0	86	0	0	0	0	0	0	900	142	0
Caloneis madraspatensis	0	0	0	0	0	0	0	0	0	0	0	71	0
Pleurosigma angulatum	1250	0	0	0	0	0	0	0	0	0	0	0	0
Nitzschia pungens	0	2425	0	0	0	0	0	0	0	0	0	0	12000
Nitzschia seriata	0	0	14000	0	0	63	161	0	82	0	180	0	0
Nitzschia sigma	0	0	0	0	0	0	808	240	0	5250	0	142	0
Nitzschia lanceolata	0	0	0	0	0	0	0	0	320	750	180	71	0
Nitzschia vitrea	0	0	0	0	0	0	0	0	0	0	0	71	0
Thallassionema nitzsciodes	6250	7800	0	1558	0	0	0	0	0	0	0	0	52000
Thallassiothrix frauenfeldii	0	0	18000	0	5324	0	285	1480	1720			571	0
Fragilaria oceanica	460000	0	0	173	0	0	1594	240	2490	5250	180	428	80000
Grammatophora undulata	0	0	0	0	48	0	0	0	0	0	0	0	0
Asterionella japonica	0	0	0	0	0	0	0	0	0	0	0	0	22000
Diatoms	**566250**	**172100**	**7246000**	**2423**	**48807**	**8466**	**6530**	**7950**	**15670**	**45000**	**2160**	**4565**	**482000**
Noctiluca scintillans	0		0	0	0	0	0	0	0	0	0	0	102000
Dinophysis caudata	0	420	0	0	0	0	1070	240	0	0	0	0	0
Ceratium furca	0	0	0	0	0	0	0	0	0	0	900	0	0
Peridinium spp	0	0	0	0	0	0	770	0	82	0	0	0	0
Peridinium pentagonum	0	0	0	0	0	0	0	0	0	750	0	0	0
Peridiniopsis sps	0	0	0	0	0	0	0	0	0	0	0	142	0
Peridinium elongatum	0	0	0	0	0	0	0	0	0	0	0	71	0
Peridiniumangulatum	0	0	0	0	0	0	0	0	0	0	0	71	0
Peridinium oceanicum	0	0	0	0	0	0	0	0	0	0	0	71	0
Diplopsalis lenticula	0	0	0	0	0	0	0	0	0	750	0	0	0
Prorocentrum micans	0	0	0	173	0	0	0	0	0		0	0	0
Dinoflagellates	**0**	**420**	**0**	**173**	**0**	**0**	**1840**	**240**	**82**	**1500**	**900**	**355**	**102000**
Trichodesmium spp	0	0	0	0	980	1600	2500	1480	0	750	0	0	0
Blue green algae	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	3420	0	0
Cyanophyta	0	0	0	0	980	1600	2500	1480	0	750	0	0	0
Total	**566250**	**172520**	**7246000**	**2596**	**49787**	**10066**	**10870**	**9670**	**15752**	**47250**	**6480**	**4920**	**584000**

Table. 1.9b. Results of the quantitative analysis of phytoplankton at Vizhinjam bay from August 2002-August2003 (Density in cells l^{-1})

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July	Aug
Chaetoceros curvisetus	0	82250	8400000	0	179	0	0	0	0	1680	194	980	235000
Chaetoceros lorenzianus	0	12000		0	0	0	0	0	0	0	0	0	0
Chaetoceros affinis	0	0	120000	0	0	0	0	0	0	0	0	0	0
Chaetoceros wighamii	0	0	120000	0	0	0	0	0	0	0	0	0	0
Chaetoceros socialis	0	0	0	0	0	0	0	0	0	2640	0	0	0
Chaetoceros decipiens	0	0	0	0	0	0	0	0	0	1920	0	0	55000
Coscinodiscus sublineatus	70000	0	12000	0	0	0	0	0	0	0	0	0	0
Coscinodiscus spp	0	128500	0	193	0	0	0	0	1028	2160	0	5428	5500
Coscinidiscus oculus iridis	0	0	8000	0	0	0	0	0	0	0	0	0	0
Eucampia zodiacus	0	0	0	0	0	0	0	5420	0	0	0	0	0
Biddulphia mobiliensis	12000	0	16000	0	1983	0	0	320	5142	0	0	0	2275
Biddulphia tuomeyi	2000	0	8000	0	0	0	0	0	0	0	0	0	0
Biddulphia delicatissima	0	0	4000	0	0	0	0	0	0	0	0	0	0
Biddulphia sinensis	0	0	8000	0	0	0	0	0	0	0	0	0	2275
Triceratium favus	28000	1250	4000	0	5036	1200	3240	0	0	0	0	980	0
Triceratium reticulum	0	0	0	0	0	0	0	0	0	0	0	85	0
Triceratium favus	0	0	0	0	0	0	0	2340	0	0	0	0	0
Hemidiscus sp[	0	0	12000	0	0	0	0	0	0	0	0	0	0
Leptocylindrus danicus	0	0	4000	0	0	0	0	0	0	5280	0	0	0
Ditylum sol	0	0	4000	0	0	0	0	0	11850	0	0	0	0
Bellarochea malleus	6000	0	0	0	0	0	0	0	0	0	0	85	0
Rhizosolenia styliformis	0	1250		0	0	0	0	4680	0	0	0	0	0
Rhizosolenia crassispina	0	0	4000	0	0	0	0	0	0	0	0	0	0
Rhizosolenia alata	0	0	8000	0	179	0	0	2240	0	0	0	85	0
Melosira sulcata	0	0	0	64	0	0	0	0	343	0	0	2253	2275
Stephanopyxis palmeriana	4000	0	12000	0	0	0	0	0	0	0	0	0	0
Planktionella sol	0	0	4000	0	0	0	0	0	0	0	0	0	0
Thalassiosira decipiens	0	0	0	0	0	85	0	0	0	0		0	0
Thalassiosira coramandelina	0	0	0	0	0	0	2755	0	0	0	0	0	0
Thalassiosira subtilis	0	0	0	0	0	0	0	0	0	0	0	0	0
Skeletonema costatum	0	0	0	0	89	5400	21585	0	0	0	0	0	0
Hyalodiscus sp	0	0	0	0	0	0	0	0	343	0	0	0	0
Hemiaulus sinensis	0	0	0	0	0	0	0	0	0	0	194	0	0
Actinoptychus splendens	2000	0				0	0	0	0	0	0	0	0
Navicula spp	0	0	0	0	0	0	0	0	343	16320	0	0	0
Pleurosigma directum	0	0	0	129	0	0		0		0	0	0	
Pleurosigma normani	0	0	0	0	0	0	860		686	0	0	0	0
Pleurosigma elongatum	0	0	0	0	0	0	0	0	0	0	0	0	4550
Nitzschia pungens	0	2580	0	0	0	0	0	0	0	4560	0	0	8500
Nitzschia seriata	0	0	92000	0	0	0	1532	0	0	0	0	0	0
Nitzschia sigma	0	0	0	0	0	0	1532	0	0	0	388	0	0
Nitzschia lanceolata	0	0	0	0	0	0	0	0	0	0	194	0	0
Nitzschia panduriformes	0	0	0	0	0	0	0	0	0	0	194	0	0
Thalassionema nitzschioides	10000	0	8000	0	0	0	0	0	0	0	0	85	45250
Thalassiothrix frauenfeldii	0	0	28000	64	12060	1440	1532	2560	343	0	0	85	4550
Fragilaria oceanica	498000	0	8000	129	5036	1080	860		1714	4320	583	2492	71000
Grammatophora undulata	0	0	0	0	0	0	0	0	0	0	194	0	0
Asterionella japonica	0	0	0	0	0	0	0	0	0	0	0	0	4550
Diatoms	**632000**	**227830**	**8884000**	**579**	**24562**	**9205**	**33896**	**17560**	**21792**	**38880**	**1941**	**12558**	**440725**
Noctiluca scintillans	0	0	0	0	0	0	0	0	0	0	0	0	55000
Ornithocercus magnifcus	0	0	4000	0	0	0	0	0	0	0	0	0	0
Dinophysis caudata	0	525	2800	64	0	0	2490	320	0	0	0	152	0
Dinophysis miles	0	0	4000	0	179	0	0	0	0	0	0	0	0
Ceratium furca	0	0	4000	64	0	0	0	0	0	0	0	0	0
Ceratium breve	0	0	0	0	0	0	428	0	0	0	0	0	0
Ceratium spp	0	0	0		0	85	0	0	0	0	0	0	0
Peridinium claudicans	2000	0	8000	129	0	0	2180	0	0	0		152	0
Peridinium spp	0	0	0	0	0	0	860	0	0	0	194	0	0
Dinoflagellates	**2000**	**525**	**22800**	**257**	**179**	**85**	**5958**	**320**	**0**	**0**	**194**	**304**	**55000**
Trichodesmium spp	0	0	0	0	0	0	0	2240	0	0	0	0	0
Blue green algae	0	0	0	0	0	0	0	0	0	0	971	0	0
Cyanophyta	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2240**	**0**	**0**	**971**	**0**	**0**
Others	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**634000**	**228355**	**8906800**	**836**	**24741**	**9290**	**39854**	**20120**	**21792**	**38880**	**3106**	**12862**	**495725**

Table.1.10a.Phytoplankton diversity and evenness indices for Vizhinjam sea from Oct 01 to August 2003.

	Species number			Richness	Evenness	Shannon-Wiener		
	Total	Diatom	Dinoflagellate	Margalef's	Pileou's	Total	Diatom	Dinoflagellate
Oct	24	14	10	5.04	0.68	2.17	1.67	1.71
Nov	20	18	2	4.22	0.90	2.67	2.57	0.69
Dec	18	7	10	3.72	0.78	2.25	1.17	1.75
Jan	26	11	14	5.45	0.71	2.32	1.78	2.49
Feb	10	6	4	1.98	0.8	1.85	1.22	1.36
March	14	8	6	2.84	0.77	2.04	1.58	1.7
April	25	21	3	5.33	0.86	2.75	2.59	1.04
May	16	15	1	3.26	0.41	1.15	1.12	0
June	9	9	0	1.74	0.62	1.37	1.37	0
July	29	28	1	6.1	0.71	2.4	2.38	0
Aug	17	17	0	3.48	0.34	0.96	0.96	0
Sept	14	7	7	2.82	0.56	1.48	1.26	1.66
Oct	21	16	5	4.39	0.56	1.72	1.54	1.16
Nov	22	16	6	4.59	0.73	2.25	1.95	1.08
Dec	27	23	4	5.8	0.68	2.25	2.13	1.39
Jan	22	18	3	4.6	0.6	1.85	1.6	1.1
Feb	30	20	9	6.36	0.81	2.75	2.39	1.83
March	28	23	4	5.86	0.85	2.84	2.64	1.08
April	24	22	2	5.07	0.71	2.24	2.19	0.69
May	25	23	2	5.22	0.64	2.06	2.01	0.69
June	24	23	1	5.07	0.65	2.06	2.02	0
July	21	18	3	4.43	0.9	2.74	2.56	1.01
Aug	12	11	1	2.39	0.78	1.95	1.8	0

Table.1.10b. Diversity and evenness indices for Vizhinjam bay from Oct 01 to August 2003.

	Species number			Richness	Evenness	Shannon-Wiener		
	Total	Diatom	Dinoflagellate	Margalef's	Pileou's	Total	Diatom	Dinoflagellate
Oct	20	13	7	4.13	0.61	1.81	1.35	1.17
Nov	21	18	3	4.35	0.92	2.8	2.64	0.95
Dec	35	14	21	7.59	0.83	2.95	1.92	2.63
Jan	12	9	3	2.39	0.79	1.97	1.69	0.95
Feb	13	5	8	2.61	0.72	1.84	1.21	1.68
March	17	4	13	3.48	0.68	1.93	1.05	2.02
April	15	10	4	3.04	0.89	2.41	2.06	1.28
May	4	4	0	0.65	0.34	0.48	0.48	0
June	20	18	2	4.13	0.5	1.49	1.45	0.64
July	19	19	0	3.96	0.53	1.57	1.57	0
Aug	14	13	1	2.83	0.48	1.26	1.17	0
Sept	14	8	6	2.82	0.62	1.64	1.48	1.79
Oct	14	12	2	2.83	0.66	1.73	1.58	0.6
Nov	23	19	4	4.8	0.67	2.11	1.97	1.32
Dec	34	25	9	7.31	0.84	2.98	2.66	2.07
Jan	38	25	13	8.15	0.89	3.24	2.79	2.48
Feb	23	15	8	4.85	0.9	2.81	2.46	1.65
March	23	17	6	4.78	0.79	2.47	2.11	1.32
April	24	19	5	4.99	0.65	2.06	1.86	1.61
May	20	19	1	4.13	0.79	2.37	2.29	0
June	21	18	3	4.34	0.63	1.91	1.82	1.1
July	19	17	2	4.02	0.86	2.54	2.38	0.69
Aug	30	26	4	6.29	0.8	2.7	2.57	0.6

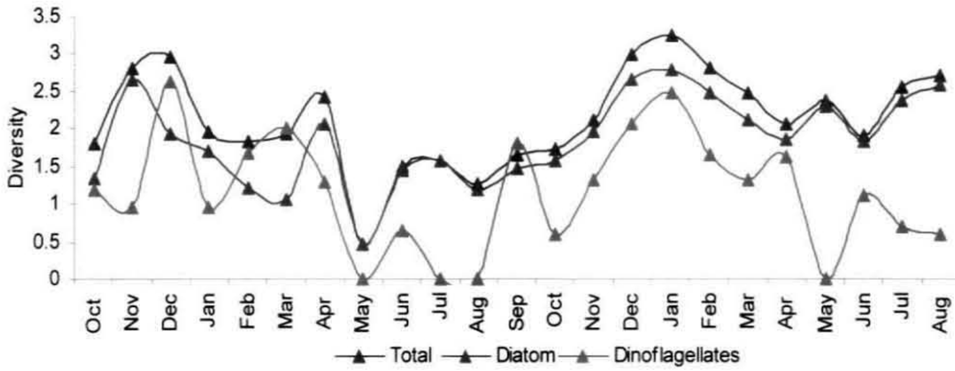


Fig.1.14a. Variation in Shannon- Wiener diversity at Vizhinjam sea from Oct 01 to August 03.

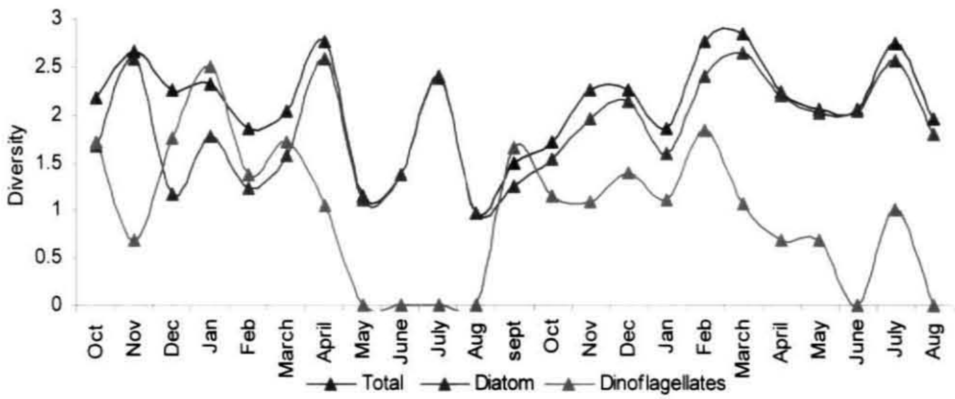


Fig.1.14b. Variation in Shannon- Wiener diversty at Vizhinjam bay from Oct 01 to August 03.

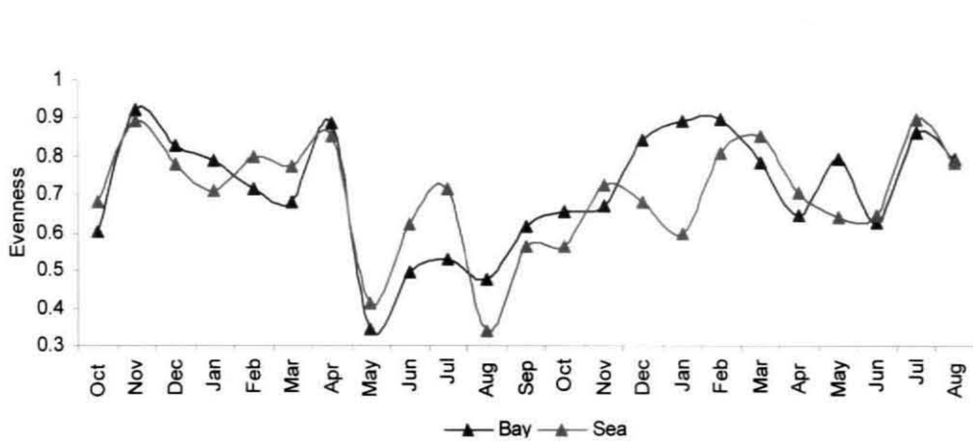


Fig.1.15.Variation in evenness at Vizhinjam bay and sea from Oct 01 to August 03.

In the second year there were 4 clusters at 40 % similarity. Cluster I consisted of the months November and March and cluster II consisted of the months January and February. The species similarity in these months were contributed by both diatoms and dinoflagellates with dinoflagellates being more prominent in cluster II. Cluster III consisted of the months October 2002 and April to August 2003. The species which were the most common to all these months were all diatoms with *Chaetoceros curvisetus* the most common. December formed a separate cluster as some species which were unique like *Rhizosolenia setigera, Dinophysis miles, Trichodesmium, R. hebetata, Chaetoceros indicus, T. reticulum* were present in the community.

In the sea, there were only three clusters. The month of May which formed a distinct cluster in the bay was present in cluster III along with the months from May to August and November. Cluster I consisted of the months October, February and March and cluster II consisted of the September, December and January. Dinoflagellates contributed 40 % to the similarity in the two clusters. Cluster II consisted of *Trichodesmium spp* also. Cluster III was composed exclusively of diatoms.

In the second year, there were four clusters with the month of January forming a separate and distinct group. The species diversity was the highest in this month as mentioned earlier, with some species like *Bacteriastrum elongatum*, *Coscinodiscus oculus-iridis, Pleurosigma elongatum, Ceratium contortum* and *Peridiniopsis* unique to this month. Cluster II consisted of the monsoon months of July and August and was composed exclusively of diatoms. Cluster III consisted of the post-monsoon months from October to December and the months from April to June. There was a 7 % contribution by dinoflagellates to the similarity in this cluster, the rest being contributed by diatoms. The fourth cluster consisted of the months February and March. The similarity of these months were due to the *Trichodesmium erythraeum* and the dinoflagellate *Dinophysis caudata*.

The dendogram showing the clusters of first year in the sea is given in Fig.1.16a and that of the second year in Fig. 1.16b. The dendogram for the first year for bay is given in Fig. 1.17a and that of second year in Fig. 1.17b. The results of SIMPER analysis of sea is given in Table. 1.11a and b and that of bay in Table. 1.12a and b.

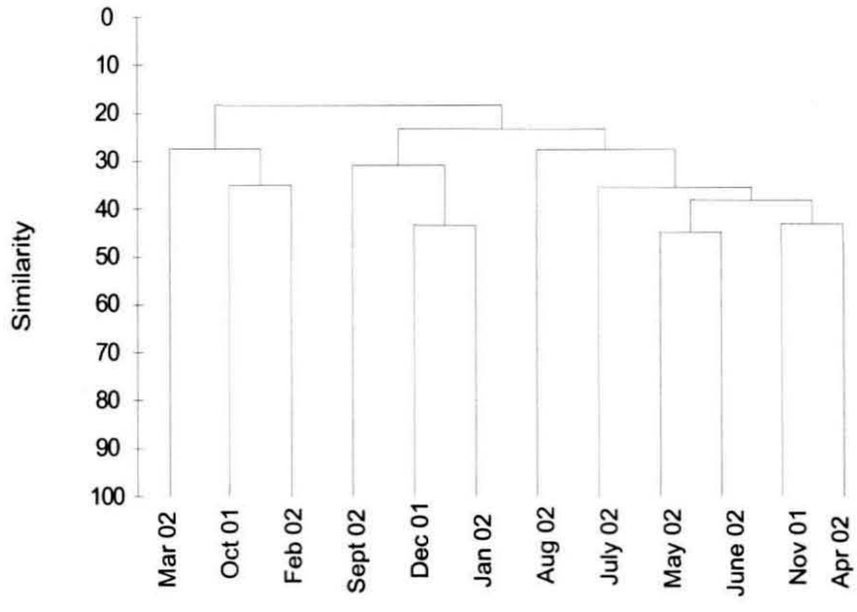


Fig. 1.16a. Dendrogram for hierarchial clustering of the months based on species abundance at Vizhinjam sea from October 2001 to September 2002.

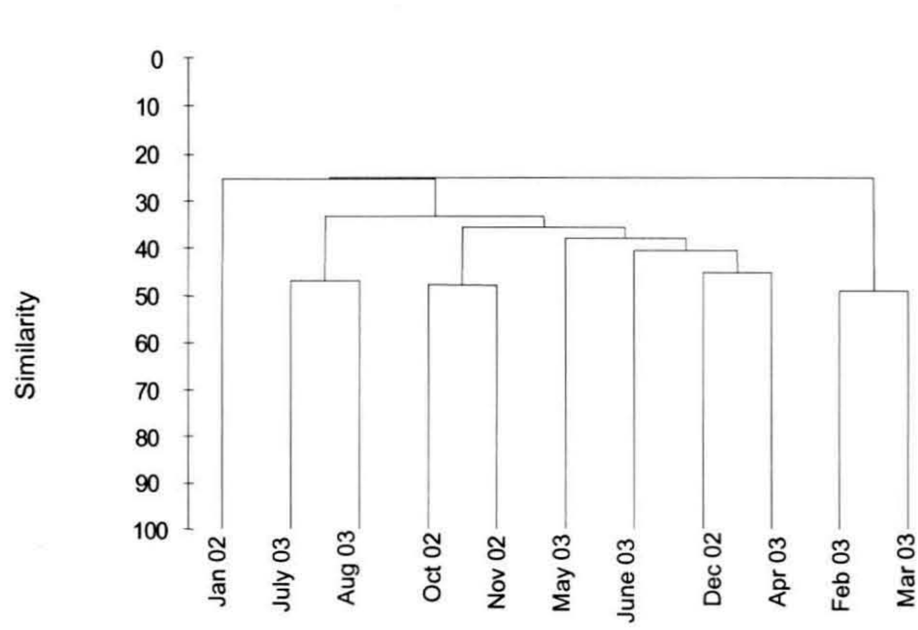


Fig. 1.16b. Dendrogram for hierarchial clustering of the months based on species abundance at Vizhinjam sea from October 2001 to September 2002.

Table.1.11a. Results of the analysis of species contributions to the average similarity within each cluster at Vizhinjam sea for the period from October 2001 to September 2002.

Group I (October 01 , February 02, March 02)					
Average similarity: 29.81					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Triceratium favus	10.8	7.79	6.46	26.14	26.14
Dinophysis caudata	6.77	6.52	4.83	21.88	48.02
Thalassiosira subtilis	17.67	3.41	0.58	11.43	59.45
Peridinium claudicans	3.93	2.86	0.58	9.61	69.06
Rhizosolenia styliformis	8.1	2.21	0.58	7.42	76.48
Peridinium divergens	1.6	1.69	0.58	5.66	82.14
Ornithocercus magnificus	1.96	1.35	0.58	4.54	86.68
Fragilaria oceanica	1.82	1.35	0.58	4.54	91.21
Group II (September 02, December 01, January 02)					
Average similarity: 34.98					
Coscinodiscus sublineatus	21.15	5.46	3.23	15.6	15.6
Coscinodiscus spp	19	5.08	4.64	14.53	30.12
Dinophysis caudata	9.67	4.96	11.96	14.19	44.31
Biddulphia mobilensis	2.36	3.6	8.73	10.28	54.59
Dinophysis miles	2.22	3.35	14.16	9.58	64.17
Ceratium tripos	1.02	3.35	14.16	9.58	73.75
Triceratium favus	10.01	1.33	0.58	3.81	77.56
Ceratium trichoceros	0.76	1.21	0.58	3.45	81.01
Ceratium breve	0.76	1.21	0.58	3.45	84.46
Pyrophacus horologium	0.87	1.09	0.58	3.11	87.57
Trichodesmium erythraeum	2.07	1.09	0.58	3.11	90.67
Group III (April, May, June, July, August 02, November-01)					
Average similarity: 34.72					
Biddulphia mobilensis	2.48	4.41	5.14	12.69	12.69
Coscinodiscus sublineatus	6.67	4	1.32	11.52	24.21
Chaetoceros curvisetus	16.81	3.78	1.1	10.88	35.09
Melosira sulcata	5.48	3.5	1.2	10.09	45.18
Triceratium favus	2.32	2.82	1.22	8.12	53.31
Rhizosolenia alata	1.91	2.72	1.25	7.83	61.14
Bellarochea malleus	1.1	1.74	0.77	5.02	66.16
Chaetoceros eibeini	12.87	1.54	0.47	4.45	70.61
Biddulphia sinensis	1.18	1.38	0.78	3.97	74.58
Coscinodiscus sublineatus	3.75	1.32	0.48	3.8	78.39
Chaetoceros affinis	3.52	0.88	0.48	2.55	80.93
Nitzschia seriata	2.33	0.84	0.48	2.42	83.35
Leptocylindrus danicus	0.6	0.72	0.48	2.07	85.42
Fragilaria oceanica	13.18	0.7	0.46	2.02	87.44
Ditylum sol	3.14	0.64	0.48	1.85	89.28
Rhizosolenia styliformis	0.59	0.6	0.48	1.72	91

Table.1.11b. Results of the analysis of species contributions to the average similarity within each cluster at Vizhinjam sea for the period from October 2002 to August 2003.

Group I (January)					
Less than 2 samples in group					
Group II (July, August)					
Average similarity: 46.80					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Fragilaria oceanica	13	7.5	-	16.03	16.03
Thalassionema nitzschioides	6.45	6.1	-	13.04	29.06
Chaetoceros curvisetus	14.55	5.53	-	11.81	40.87
Asterionella japonica	2.3	4.61	-	9.85	50.73
Nitzschia pungens	2.45	4.61	-	9.85	60.58
Melosira sulcata	4.1	4.61	-	9.85	70.44
Chaetoceros lorenzianus	1.6	4.61	-	9.85	80.29
Biddulphia obtusa	1.6	4.61	-	9.85	90.15
Group III (October, November, May, June, December, April)					
Average similarity: 38.12					
Chaetoceros curvisetus	24.32	6.39	4.55	16.77	16.77
Ditylum sol	10.11	3.74	3.44	9.81	26.58
Thallassiothrix frauenfeldii	6.23	2.63	1.26	6.9	33.48
Chaetoceros lorenzianus	4.22	2.49	1.33	6.52	40
Fragilaria oceanica	4.41	2.42	1.25	6.36	46.36
Rhizosolenia alata	1.1	2.24	1.34	5.88	52.24
Triceratium favus	1.21	2.18	1.36	5.71	57.95
Biddulphia sinensis	0.68	2.13	1.36	5.6	63.54
Biddulphia mobilensis	2.23	1.39	0.79	3.63	67.18
Peridinium spp	0.9	1.36	0.79	3.57	70.75
Asterionella japonica	1.26	1.3	0.79	3.41	74.16
Actinoptychus splendens	0.43	1.18	0.79	3.09	77.24
Nitzschia pungens	11.43	1.12	0.45	2.94	80.18
Skeletonema costatum	3.33	0.81	0.47	2.13	82.31
Rhizosolenia styliformis	0.55	0.71	0.48	1.86	84.17
Lauderia annulata	1.16	0.65	0.48	1.7	85.87
Pyrophacus horologium	0.35	0.63	0.48	1.66	87.53
Dinophysis caudata	2.06	0.63	0.48	1.64	89.17
Group IV(February, March)					
Average similarity: 48.88					
Trichodesmium erythraeum	15.6	5.22	-	10.68	10.68
Dinophysis caudata	6.65	4.28	-	8.76	19.44
Nitzschia sigma	4.65	3.76	-	7.7	27.13
Thalassiothrix frauenfeldii	7	3.48	-	7.13	34.26
Fragilaria oceanica	6.65	3.41	-	6.98	41.24
Actinoptychus undulatus	3.25	3.41	-	6.98	48.22
Nitzschia seriata	2	3.16	-	6.47	54.69
Bellarochea malleus	1.85	2.9	-	5.93	60.62
Peridinium spp	1.83	2.87	-	5.87	66.49
Ceratium breve	1.43	2.87	-	5.87	72.36
Pleurosigma normanii	1.43	2.87	-	5.87	78.23
Ceratium furca	1	2.66	-	5.44	83.67
Rhizosolenia alata	6.18	2.66	-	5.44	89.12

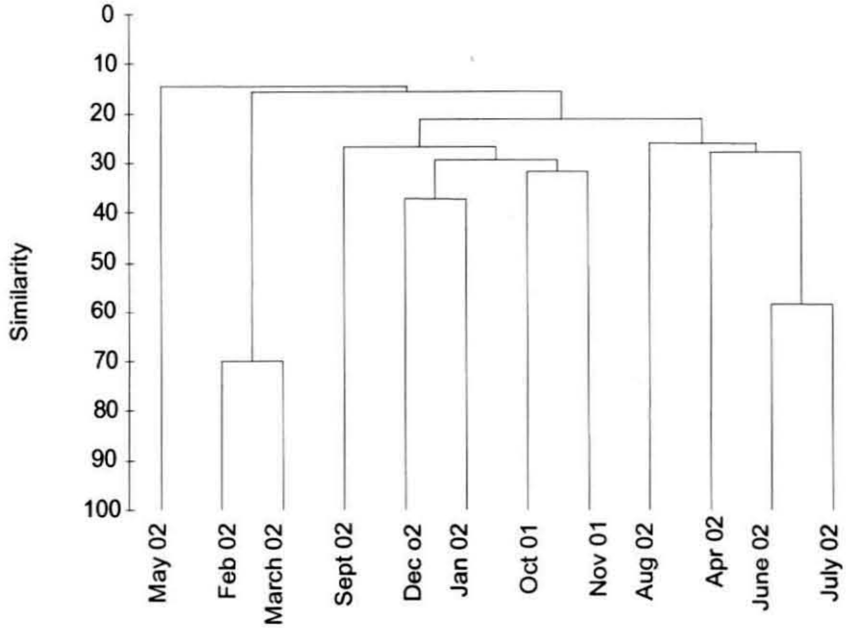


Fig.1.17a.Dendrogram for hierarchial clustering of the months based on species abundance at Vizhinjam bay from October 2001 to September 2002

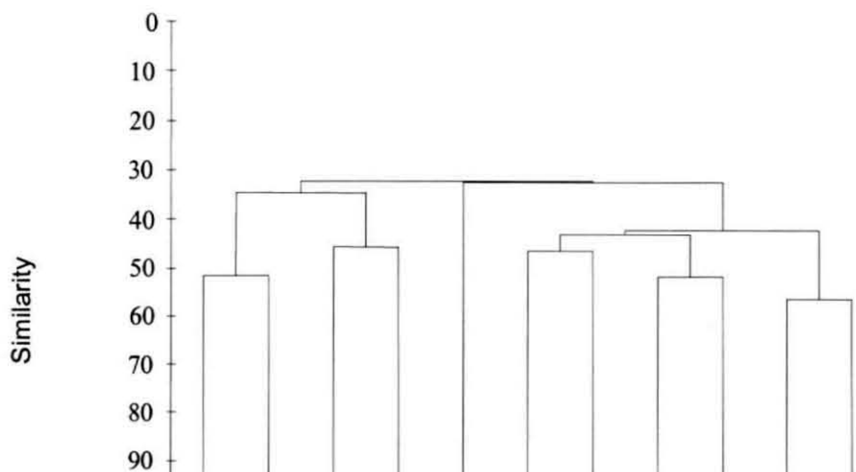


Fig.1.17 b.Dendrogram for hierarchial clustering of the months based on species abundance at Vizhinjam bay from October 2002 to August 03.

Table.1.12a. Results of the analysis of species contributions to the average similarity within each cluster at Vizhinjam bay for the period from October 2001 to September 2002.

Group I (May)					
Less than 2 samples in group					
Bloom of *Chaetoceros curvisetus*					
Group II (February, March)					
Average similarity: 69.99					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Chaetoceros affinis	28.5	10.92	-	15.6	15.6
Dinophysis caudata	11.5	8.84	-	12.63	28.22
Thalassiosira subtilis	22.4	8.43	-	12.04	40.27
Rhizosolenia alata	15.5	6.37	-	9.1	49.36
Pyrophacus horologium	1.26	5.06	-	7.23	56.6
Peridinium murrayi	1.26	5.06	-	7.23	63.83
Peridinium oceanicum	1.26	5.06	-	7.23	71.06
Ceratium furca	1.96	5.06	-	7.23	78.3
Ceratium horridum	1.26	5.06	-	7.23	85.53
Ceratium macroceros	1.26	5.06	-	7.23	92.77
Group III (Sept, Dec, Jan, Oct, Nov)					
Average similarity: 29.44					
Dinophysis caudata	7.86	5.3	3.48	17.99	17.99
Triceratium favus	11.1	4.62	3.54	15.68	33.67
Coscinodiscus sublineatus	10.83	3.5	1.04	11.87	45.55
Biddulphia mobiliensis	3.56	3.09	1.08	10.51	56.06
Rhizosolenia styliformis	6.26	2.01	0.62	6.83	62.89
Rhizosolenia alata	6.07	1.94	1.09	6.59	69.48
Ceratium breve	0.85	1.78	1.12	6.06	75.54
Thalassiothrix frauenfeldii	2.6	1.17	0.6	3.97	79.51
Rhabdonema mirificum	2.12	1.17	0.6	3.97	83.47
Dinophysis miles	0.85	1.14	0.6	3.86	87.33
Ornithocercus magnificus	0.85	1.14	0.6	3.86	91.19
Group IV					
Average similarity: 32.11(April, June, July, August)					
Coscinodiscus sublineatus	17.33	7.86	5.06	24.49	24.49
Thalassionema nitzschioides	10.62	5.64	4.53	17.56	42.05
Triceratium favus	3.9	4.65	3.01	14.49	56.54
Fragilaria oceanica	19.89	2.67	0.77	8.31	64.85
Chaetoceros eibeini	15.73	2.5	0.82	7.79	72.64
Bellarochea malleus	0.79	2.04	0.89	6.35	79
Melosira sulcata	1.95	1.09	0.41	3.39	82.39
Nitzschia seriata	1.66	0.98	0.41	3.07	85.46
Biddulphia pulchellum	2.62	0.71	0.41	2.22	87.68
Biddulphia mobiliensis	0.5	0.67	0.41	2.09	89.76
Bacteriastrum varians	0.46	0.65	0.41	2.04	91.8

Table.1.12b. Results of the analysis of species contributions to the average similarity within each cluster at Vizhinjam bay for the period from October 2002 to August 2003.

Group I (November, March)	**Average similarity: 51.64**				
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Rhizosolenia styliformis	15.29	6.11	-	11.83	11.83
Thalassiothrix frauenfeldii	17.3	4.92	-	9.52	21.36
Dinophysis caudata	5.4	4.07	-	7.89	29.25
Thalassionema nitzschioides	14.56	3.73	-	7.22	36.46
Chaetoceros diversus	2.71	3.73	-	7.22	43.68
Chaetoceros curvisetus	1.36	3.73	-	7.22	50.9
Peridinium claudicans	1.06	3.62	-	7.01	57.91
Grammatophora undulata	0.83	3.11	-	6.01	63.92
Rhizosolenia berganii	0.83	3.11	-	6.01	69.94
Rhizosolenia alata	6.02	3.11	-	6.01	75.95
Eucampia zodiacus	8.67	3.11	-	6.01	81.96
Lauderia annulata	0.83	3.11	-	6.01	87.97
Group II (January, February)					
Average similarity: 45.72					
Skeletonema costatum	12.4	4.43	-	9.69	9.69
Triceratium favus	7.75	4.3	-	9.4	19.09
Thallassiothrix frauenfeldii	5.8	4.06	-	8.89	27.98
Fragilaria oceanica	3.8	3.78	-	8.27	36.24
Nitzschia sigma	4.15	3.04	-	6.64	42.89
Pyrophacus horologium	1.88	2.96	-	6.47	49.36
Ceratium furca	2.48	2.96	-	6.47	55.83
Rhizosolenia styliformis	2.48	2.96	-	6.47	62.3
Dinophysis caudata	6	2.87	-	6.28	68.58
Ceratium breve	1.28	2.87	-	6.28	74.87
Lauderia annulata	1.35	2.87	-	6.28	81.15
Bellarochea malleus	1.28	2.87	-	6.28	87.43
Group III (April, May, June, July, August, October)					
Average similarity: 44.41					
Chaetoceros curvisetus	18.1	5.62	2.68	12.66	12.66
Thalassiothrix frauenfeldii	3.33	4.17	5.8	9.38	22.04
Peridinium claudicans	2.68	4.14	3.53	9.32	31.37
Biddulphia sinensis	1.36	3.71	9.92	8.36	39.73
Fragilaria oceanica	8.33	3.68	1.31	8.29	48.02
Nitzschia pungens	14.47	2.81	0.77	6.32	54.35
Asterionella japonica	1.55	2.58	1.35	5.81	60.15
Bellarochea malleus	2	2.48	1.29	5.59	65.75
Biddulphia mobilensis	1.12	2.46	1.35	5.53	71.28
Triceratium favus	1.13	2.37	1.33	5.34	76.62
Ditylum sol	8.79	1.7	0.79	3.83	80.45
Coscinodiscus sublineatus	7.23	1.12	0.48	2.53	82.98
Chaetoceros decipens	2.58	1	0.48	2.25	85.23
Melosira sulcata	2.68	0.87	0.48	1.96	87.19
Thalassionema nitzschioides	2.84	0.82	0.48	1.86	89.05
Group IV (December)- Less than 2 samples in group					

F. BIOLOGICAL PARAMETERS

The seasonal values and standard deviation of biological parameters at Vizhinjam bay and sea is presented in Table.1.13.

i) Productivity

Gross surface productivity at Vizhinjam sea recorded the minimum of 0.874 $gC/m^3/day$ in January and highest of 3.172 $gC/m^3/day$ in September the first year. Net productivity was minimum in January itself, 0.526 $gC/m^3/day$, while the highest was 2.442 $gC/m^3/day$ in June. Seasonally both GP and NP was minimum in post-monsoon and highest in monsoon season .The gross productivity in the second year recorded minimum value of 0.223 $gC/m^3/day$ in February and maximum of 5.173 $gC/m^3/day$ in October. Net productivity was nil in February and April whereas highest NP values were recorded in October as 3.55 $gC/m^3/day$. Seasonal values were lowest in pre-monsoon and highest in the post-monsoon season.

In the first year, the bay region recorded a minimum gross productivity and net productivity of 0.786 and 0.534 respectively in the post-monsoon month of January. Maximum GP of 3.45 was estimated in September and maximum NP of 2.415 $gC/m^3/day$ in August. The second year recorded minimum of 0.223 in January and maximum of 3.86 in October. The NP was nil in April and highest of 1.88 $gC/m^3/day$ in October. Seasonally both GP and NP were minimum in the post-monsoon season the first year and in the in the pre-monsoon season in the second year. Maximum values for both GP and NP was in the monsoon season in the first year. In the second year GP was maximum in the monsoon season while the NP was maximum in the post-monsoon season.

ii) Chlorophyll

In the first year, Chlorophyll *a* recorded a minimum of 0.148 mg m^{-3} in the sea in November and a maximum of 12.42 mg m^{-3} in September. In the second year, minimum of 0.442 mg m^{-3} was recorded in March and a maximum of 7.99 mg m^{-3} in May. Seasonal values were lowest in the post-monsoon season and highest in monsoon in the first year. The second year recorded lowest values in monsoon season and highest in pre-monsoon.

In the bay region Chlorophyll *a* concentration varied between a minimum of 0.148 mg m^{-3} in November to 22.34 mg m^{-3} in the monsoon month of September in the first year. The second year recorded a minimum of 1.240 mg m^{-3} in March and a maximum of 35.86 mg m^{-3} in October. Seasonal values were lowest for post-monsoon season and highest in the monsoon season in the first year. The second year recorded a minimum in the monsoon season and a maximum in the post-monsoon season.

Chlorophyll *b* concentration was very low in the samples from Vizhinjam sea. It was absent in the months of August and September and reached a maximum of 1.823 mg m^{-3} in January in the first year. The second year chlorophyll *b* was absent in October, February, April, May and August reaching highest of 0.205 mg m^{-3} in post-monsoon month of December. Seasonally the lowest concentration was in the monsoon season in the first year and in pre-monsoon the second year. In the bay region Chl *b* was absent in the water samples in February and August and reached a maximum of 2.725 mg m^{-3} in April 2002. Second year Chl *b* was absent in January, May and August reaching a maximum of 1.8 mg m^{-3} in October.

E. BIOTIC CORRELATIONS

GP showed positive correlation with NP (r=0.887,0.684) at sea and bay and also to humidity (r=0.582, 0.613) and TSS (r=0.532 and 0.5). GP related positively to phytoplankton cell density and rainfall (r=0.815 and 0.535) at sea. NP also showed positive correlation with phytoplankton cell density (r=0.905), humidity (r=0.471) and rainfall (r=0.63) in the sea and with rainfall (0.428) and phosphate (r=0.51) in the bay.

Chl *a* was positively correlated with NP (r=0.768), Chl *b* (r=0.478), carotenoids (r=0.867), rainfall (r=0.425) and TSS (r=0.68) in the bay. Chl *b* was positively correlated in the bay with Chl *c* (r=0.447) and pH (r=0.429) and carotenoids (r=0.524). It was negatively correlated with DO (r=0.421). Chl *c* was correlated positively with pH (r=0.423) and TSS (r=0.614) in the bay. Carotenoids were correlated positively with GP (r=0.588) and TSS (r=0.552) in the bay. Phytoplankton cell density was correlated positively with GP and NP (r=0.815, 0.905). It also showed positive correlation with rainfall (r=0.773) and TSS (r=0.725).

The results of the Pearson correlation analysis between environmental and biological parameters is presented in Table.1.14.

Table. 1.13. Seasonal values and standard deviation of biological parameters at Vizhinjam bay and sea for the period from October 2001 to August 2003.

	BAY						SEA					
Month	Productivity		Chlorophyll				Productivity		Chlorophyll			
	GP	NP	*a*	*b*	*c*	Carotenoids	GP	NP	*a*	*b*	*c*	Carotenoids
	$gC/m^3/day)$		mg/m^3				$gC/m^3/day)$		mg/m^3			
Post M I												
Average	0.96	0.84	0.82	0.86	0.37		1.28	0.65	1.17	0.69	0.05	......
Std dev	0.11	0.18	0.85	0.55	0.53		0.41	0.15	1.72	0.81	0.11	......
Pre M I												
Average	1.05	0.87	1.20	0.76	2.02		1.44	0.83	2.54	0.60	1.62	0.03
Std dev	0.17	0.19	1.28	1.32	3.71		0.32	0.15	1.80	0.50	1.71	
Monsoon I												
Average	2.76	1.39	9.07	0.73	0.49	0.12	2.83	1.47	6.70	0.14	0.68	0.10
Std dev	0.59	0.70	9.02	1.17	0.55	0.09	0.34	0.69	4.33	0.17	0.53	0.12
Post M II												
Average	1.71	1.10	11.29	0.97	0.39	0.19	1.96	1.37	3.02	0.06	0.49	0.08
Std dev	1.57	0.60	16.38	0.87	0.38	0.16	2.19	1.48	0.68	0.10	0.46	0.05
Pre M II												
Average	1.07	0.65	3.58	0.30	0.72	0.09	0.81	0.36	3.80	0.04	1.14	0.11
Std dev	0.33	0.46	2.44	0.37	0.55	0.05	0.46	0.42	3.43	0.08	1.41	0.08
Monsoon II												
Average	1.91	1.04	2.75	0.14	0.46	0.09	1.82	0.98	2.79	0.10	0.42	0.11
Std dev	0.44	0.03	1.89	0.15	0.42	0.09	0.49	0.10	1.86	0.09	0.41	0.08

Table. 1.14. Results of Pearson correlation analysis between biological and environmental parameters at Vizhinjam

	SEA	BAY	SEA	BAY	BAY	BAY	SEA	BAY	BAY	BAY	SEA
	GP	GP	NP	NP	Chl a	Chl b	Chl c	Chl c	Carot-	Cell	Cell
									enoids	density	density
GP			0.887**						0.588*	0.815**	0.615**
NP	0.887**	0.684**			0.768**					0.905**	0.825**
Chl *b*					0.478*						
Chl *c*						0.447*					
Carotenoids					0.867**	0.524*					
Cell density	0.815**		0.905**								
Dissolved Oxygen						-0.421*					
pH				-0.526**		0.429*	0.423*				
Humidity	0.582**	0.613**	0.471*								
Rainfall	0.535**		0.636**	0.428*	0.425*					0.773**	0.658**
Phosphate				0.51*						0.75**	0.68**
TSS	0.532**	0.5*			0.68**			0.614**	0.552*	0.725**	

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

1.3.2. ENVIRONMENTAL PARAMETERS

1.3.2.1. CHOMBALA

The seasonal values and standard deviation of environmental parameters at Chombala is presented in Table. 1.15.

A. METEOROLOGICAL PARAMETERS

i. Rainfall

Highest amount of rainfall in the first and second years was recorded in June during the southwest monsoon season, with maximum rainfall of 667 mm and 918 mm, and in October during the northeast monsoon, with 276 mm and 573 mm respectively. The total amount of rainfall received in 2002 and 2003 was 2770 mm and 2570 mm, which was lesser than the average rainfall of 3280 mm for the Calicut region. Rainfall during southwest monsoon was highest of 1889 mm in 2003 when compared to 1700 mm in 2001 and 1560 mm in 2002.The northeast monsoon season received heavier rainfall of 760 mm in 2002, when compared to 490 mm in 2001 and 340 mm in 2003.

ii. Humidity

In the first year, the lowest humidity of 71.25% was recorded in April, whereas in the second year minimum humidity of 75.63% was recorded in December. Highest values of humidity were recorded in both the years during the southwest monsoon period and was lowest for pre-monsoon season. The monthly variation in rainfall and humidity at Chombala is presented in Fig. 1.18.

B. PHYSICOCHEMICAL PARAMETERS

i. Temperature

The atmospheric temperature (AT) ranged between 27^{o} C to 32^{o} C during the first year of the study period and between 27-33^{o} C in the second year. In the first year, the lowest temperature of 27^{o} C was recorded in January and August and the highest of 32^{o} C in March and April. In the second year the minimum atmospheric temperature of $27\,^{o}$C was recorded in March and July and the highest of $33\,^{o}$C in May. Seasonally the minimum atmospheric temperature was recorded in the post-monsoon season in the first year and in the monsoon season the second year. The maximum temperature was recorded in the pre-monsoon season the first year and in the post-monsoon season the second year.

Sea surface temperature (SST) also showed a similar pattern. It ranged between 27-34 ^{o}C in the first year and between 26-31 ^{o}C in the second year. The minimum temperature of 27 ^{o}C was recorded in August and September and a maximum of 34 ^{o}C in April.

In the second year minimum temperature of 26 °C was recorded in July and a maximum of 31 °C in October. Sea surface temperature recorded the minimum in monsoon season both the years. Maximum was in the pre-monsoon season the first year and in post-monsoon the second year. The monthly variation of AT at Chombala and Vizhinjam is given in Fig.1.19 and that of SST in Fig. 1.20.

ii. Salinity

Salinity values at Chombala fluctuated between 32 to 35 ppt during the first year and between 30-36 ppt in the second year. In the first year the minimum value of 32 ppt was recorded in the post-monsoon months of October and November and also in May, June and August. Maximum salinity of 35 ppt was recorded in March. In the second year the minimum value of 30 ppt was recorded in the monsoon month of August and the maximum salinity of 36 ppt was recorded in the pre-monsoon month of May. The first year recorded low value in both monsoon and post-monsoon seasons and highest in pre-monsoon season. The second year, seasonal value was lowest in monsoon and highest in the pre-monsoon. The monthly variation of salinity at Chombala and Vizhinjam is presented in Fig.1.21.

iii. pH

pH values of the first year ranged between a minimum of 7.05 in September to a maximum of 8.24 in October. In the second year the pH values ranged between a minimum of 8.02 in the monsoon months of July and September and 8.26 in the post-monsoon month of November. pH value was lowest in monsoon season in both the years. The first year recorded maximum pH values in both the post and pre-monsoon season and in the post-monsoon season in the second year. The monthly variation of pH at Chombala and Vizhinjam is presented in Fig. 1.22.

iv. Dissolved Oxygen

Dissolved oxygen (DO) content of the station showed an exceptionally high value of 11.70 mg l^{-1} in October 2001. Excluding this it ranged in the first year between 1.92 mg l^{-1} in September and 6.67 mg l^{-1}in January. In the second year, minimum of 1.47 mg l^{-1} was observed in September and a maximum value of 7.07 mg/l was recorded in April 2003. Seasonal values for dissolved oxygen were low in monsoon both the years and maximum in the post-monsoon season the first year and in pre-monsoon season the second year. The monthly variation of Dissolved oxygen at Chombala and Vizhinjam is presented in Fig.1.23.

v. Total Suspended Solids

Total suspended solid (TSS) content values showed wide fluctuations. In the first year, it varied between 2.5 in November to a maximum of 50.2 mg l^{-1}in August. In the second year it ranged between 2.5 mg l^{-1} in February and 45.5 mg l^{-1} in July. It was highest in monsoon both the years and minimum in the post-monsoon season. The monthly variation of TSS at Chombala is presented in Fig.1.24.

vi. Biological Oxygen Demand

Biochemical oxygen demand (BOD) fluctuated between a minimum of 0.50 mg l^{-1}, which was recorded in November to a maximum of 2.7 mg l^{-1} recorded in May and August in the first year. In the second year of study it ranged between a minimum of 1.1 mg l^{-1} in September to a maximum of 9.6 mg l^{-1} in April .The seasonal values of biochemical oxygen demand were lowest in post-monsoon season the first year and in monsoon the second year. The maximum was in monsoon the first year and in pre-monsoon season the second year. The monthly variation of BOD at Chombala and Vizhinjam is presented in Fig.1.25.

vii. Nutrients

a. Ammonia

Ammonia content showed wide fluctuations between the months, concentration varying over a wider range in the first year than in the second year of study. The first year recorded nil values in June and September . Higher values of 52.15, 22.62, 13.88 and 12.62 µmol l^{-1} were recorded in the months of November, April, December and May respectively. In the second year ammonia was absent in the months from March to May. Maximum value of 12.02 µmol l^{-1} was recorded in August. The first year recorded minimum seasonal value in the monsoon season and in pre-monsoon the second year. Maximum was in the post-monsoon season the first year and in the monsoon season the second year. The monthly variation of ammonia concentration at Chombala is presented in Fig.1.26.

b. Phosphate

Phosphate values ranged between a minimum of 0.04 µmol l^{-1} in October and a maximum of 2.99 µmol l^{-1} in August in the first year. In the second year it ranged between zero in December to a maximum of 3.59 µmol l^{-1} in January. Seasonally phosphate recorded low value the pre-monsoon season the first year and highest in the monsoon. In the second year all the seasons recorded almost similar values with the lowest in the post-monsoon season. The monthly variation of phosphate at Chombala is presented in Fig. 1.27.

c. Nitrate

Nitrate values ranged between zero to 3.50 µmol l^{-1} in the first year. Nil value was recorded in February and maximum in July and August. The second year recorded nil values in February and March and highest of 12.44 µmol l^{-1} 1 in June. The first year recorded lowest value in the post-monsoon and in the pre-monsoon season in the second year. Maximum was recorded in the monsoon season both the years. The monthly variation of nitrate at Chombala is presented in Fig.1.28.

d. Nitrite

Very low nitrite concentration was recorded in the station in both the years. Nil values were recorded in the months of April and May in the first year. Maximum concentration of 1.72 μmol l^{-1} was recorded in November. Rest of the months it fluctuated between 0.01 to 0.88 μmol l^{-1}. The second year recorded a still lower concentration of nitrite with a maximum value of 0.604 μmol l^{-1} in June 2003 and a minimum value of 0.01 μmol l^{-1} in April 2003. Seasonal value for nitrite was lowest in pre-monsoon season the first year and in the post-monsoon season the second year. The highest seasonal value in the first year was in the post-monsoon and in the monsoon season the second year. The monthly variation of nitrite at Chombala is presented in Fig.1.29.

C. ENVIRONMENTAL CORRELATIONS

SST was positively correlated with AT(r=0.74) and negatively with humidity(r=0.556), Nitrate(r=0.44) and Phosphate(r=0.438). Salinity showed negative correlation with humidity (r=0.648), Nitrate(r=0.511) and rainfall (0.584). Rainfall was positively correlated with humidity(r=0.68) and nitrate (0.564).Nitrate was correlated positively with humidity (r=0.542), nitrite with ammonia(r=0.753) and phosphate negatively with Dissolved oxygen(r=0.441). Significant correlation values between environmental parameters at Chombala is presented in Table. 1.16.

Table. 1.15. Seasonal values and standard deviation of environmental parameters at Chombala.

Month	Humidity	Rainfall	Temp		Salinity	pH	DO	TSS	BOD	Nutrients)			
			At.T	SST						NH_3	PO_4	No_3	No_2
	%	mm	(°C)		ppt			$mg\ l^{-1}$		(μ mol l^{-1})			
Post M I													
Average	81.84	87.75	28.75	29	32.5	7.99	6.84	15.88	1.43	18.41	0.51	0.72	0.72
Std dev	5.26	129.66	1.26	0.82	0.58	0.18	3.41	21.5	0.81	23.19	0.42	0.84	0.76
Pre M I													
Average	76.64	121	31.25	31.5	33.5	7.99	4.55	20.7	1.58	10.24	0.41	0.83	0.01
Std dev	4	219.66	0.96	1.73	1.29	0.09	0.73	19.5	0.87	9.69	0.22	1.24	0.01
Monsoon I													
Average	90.16	389.5	28.93	28	32.5	7.72	4.06	24.65	1.83	0.25	1.9	1.87	0.11
Std dev	4.23	221.92	1.35	1.15	0.58	0.46	1.43	18.77	0.59	0.31	1.3	1.89	0.11
Post M II													
Average	79.92	181	30.25	29.88	34	8.17	5.03	4.78	1.63	1.36	1.1	0.59	0.11
Std dev	3.9	234.57	1.79	0.74	1.22	0.07	0.46	2.88	0.71	1.18	1.67	0.62	0.06
Pre M II													
Average	79.73	89	30	29	34.5	8.15	5.34	13.03	2.18	0.79	1.29	0.06	0.16
Std dev	2.2	82.15	2.94	1.41	1	0.05	1.23	12.53	1.45	1.58	0.45	0.1	0.15
Monsoon II													
Average	89.22	472.25	28.5	27.25	31.5	8.07	3.55	22.53	1.3	8.99	1.22	9.68	0.37
Std dev	3.72	347.63	1.29	1.26	1.29	0.05	1.82	17.97	1.29	2.45	1.55	7.11	0.2

Table.1.16. Significant correlation values between environmental parameters at Chombala.

	SST	SALINITY	RAINFALL	pH	TSS	NITRATE	NITRITE	PHOSPHATE
AMMONIA							0.753**	
AT.T	0.741**							
HUMIDITY	-0.556**	-0.648**	0.68**			0.542**		
DO				0.473*				-0.441*
NITRATE	-0.44*	-0.516**	0.564**					
PHOSPHATE	-0.438*							
RAINFALL		-0.581**						
BOD					0.446*			

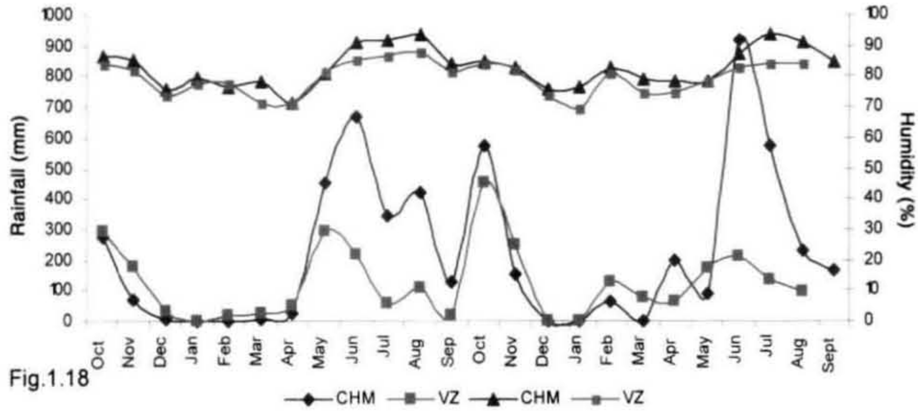


Fig.1.18

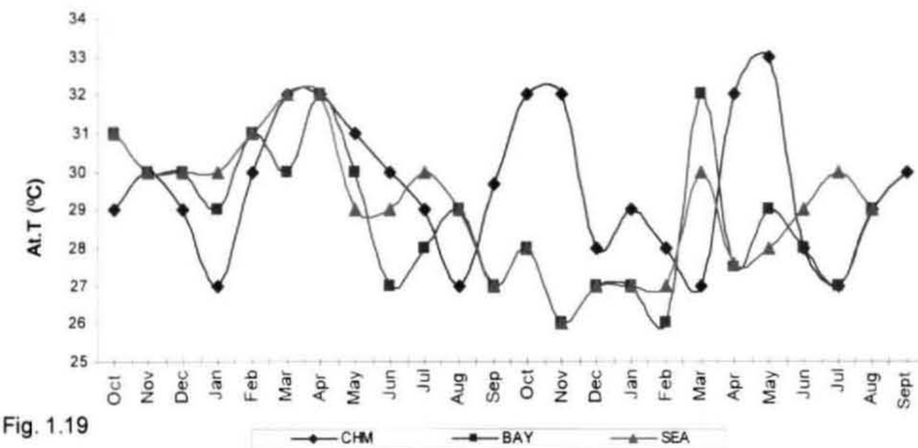


Fig. 1.19

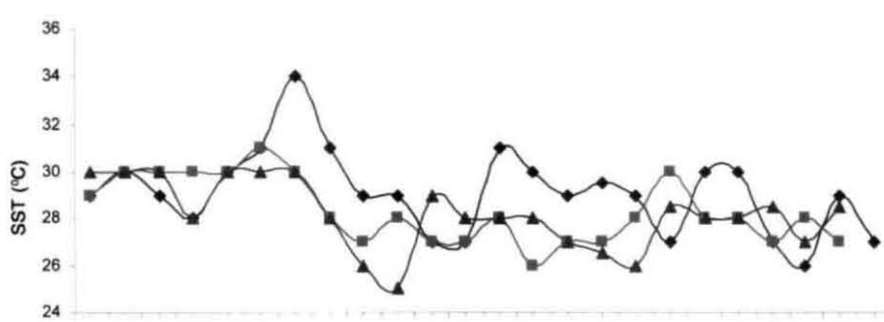


Fig. 1.20

Monthly variation of environmental parameters at Chombala, Vizhinjam bay and Vizhinjam sea
Fig.1.18. rainfall and humidity, 1.19. Atmospheric temperature and 1.20. Sea surface temperature

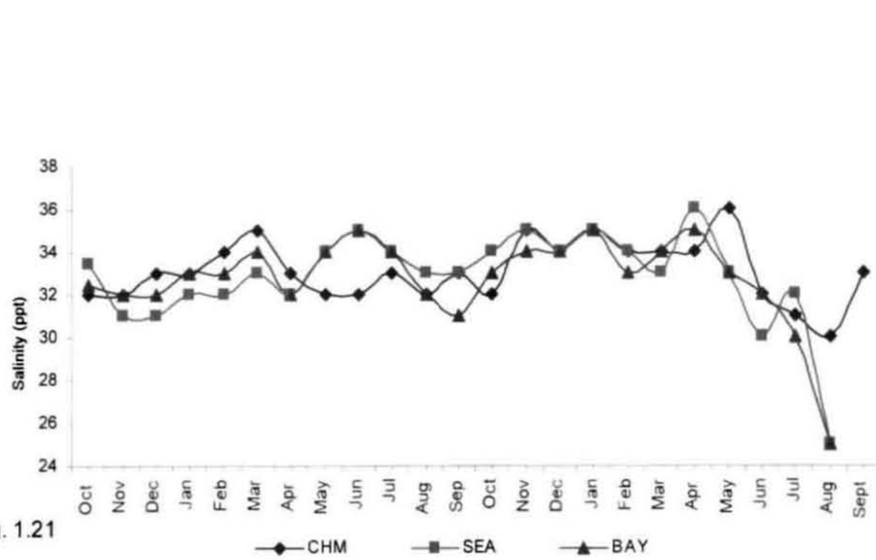


Fig. 1.21

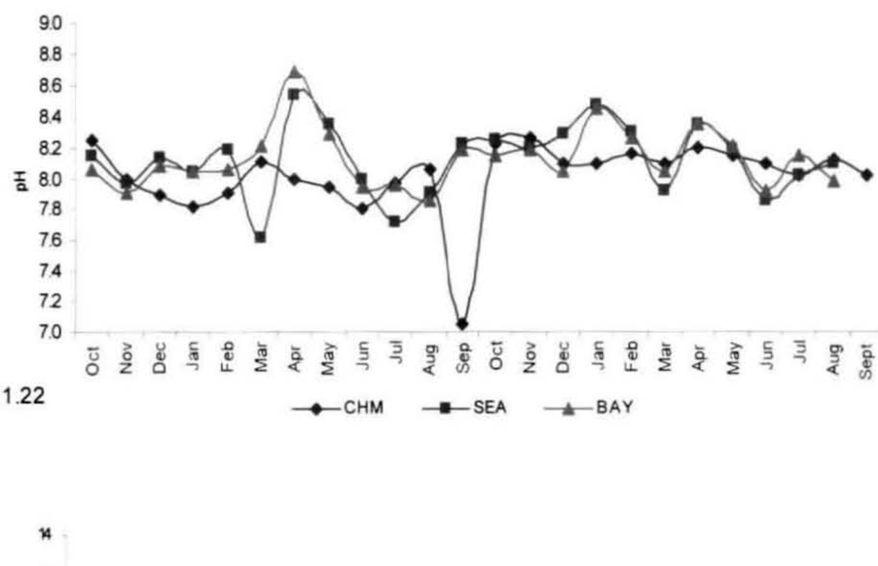


Fig. 1.22

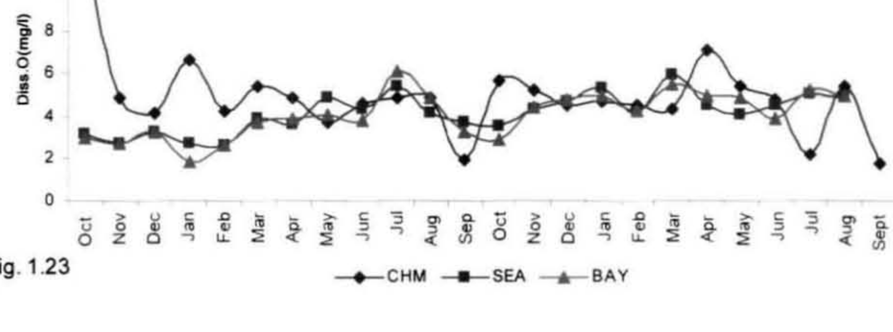
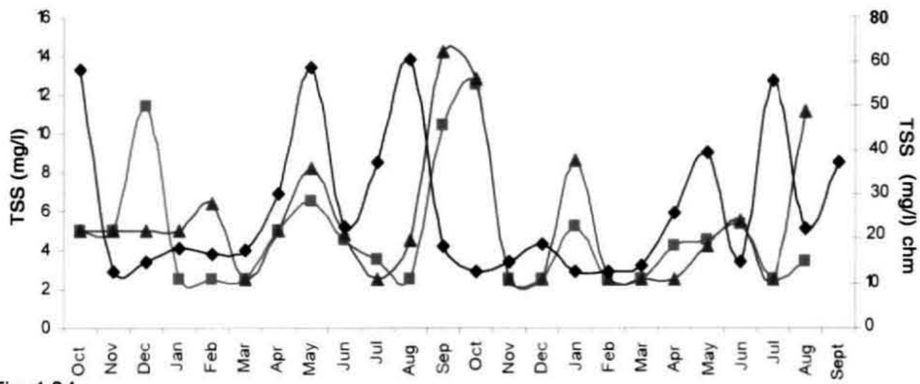


Fig. 1.23

Monthly variation of environmental parameters at Chombala, Vizhinjam bay and Vizhinjam sea
Fig.1.21. Salinity, 1.22. pH and 1.23. Dissolved oxygen



Fig, 1.24

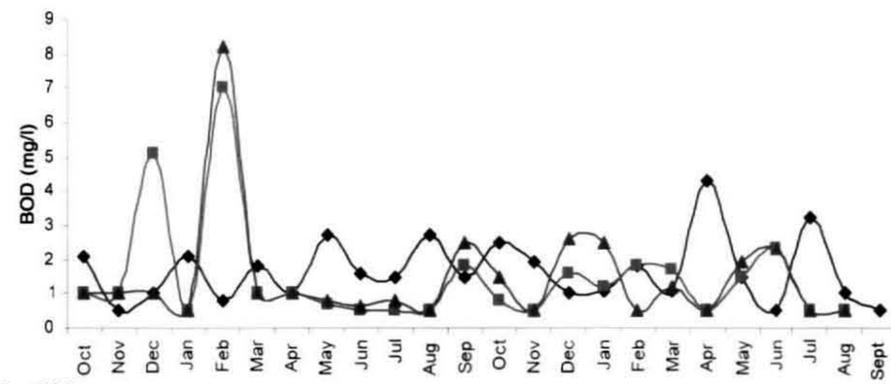


Fig. 1.25

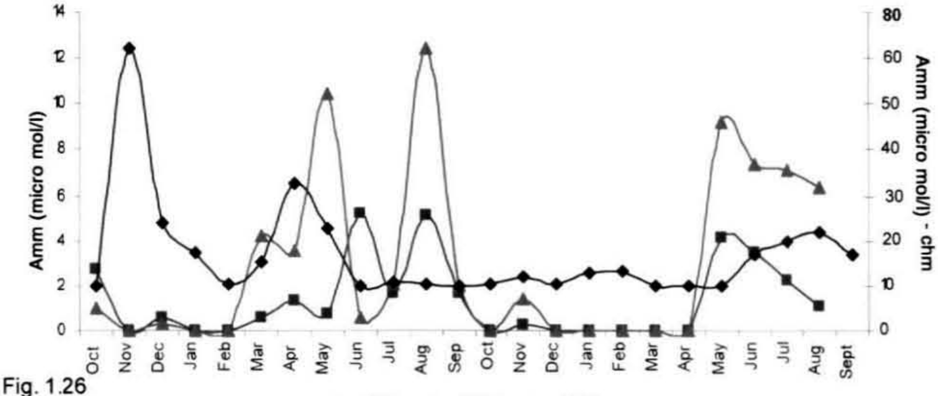


Fig. 1.26

Monthly variation of environmental parameters at Chombala, Vizhinjam bay and Vizhinjam sea
Fig.1.24. Total suspended solids, 1.25. Biological oxygen demand and 1.26. ammonia (Amm)

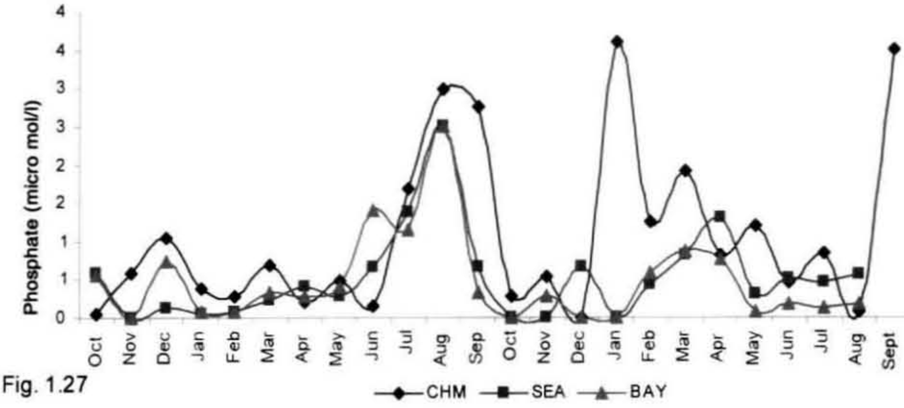


Fig. 1.27

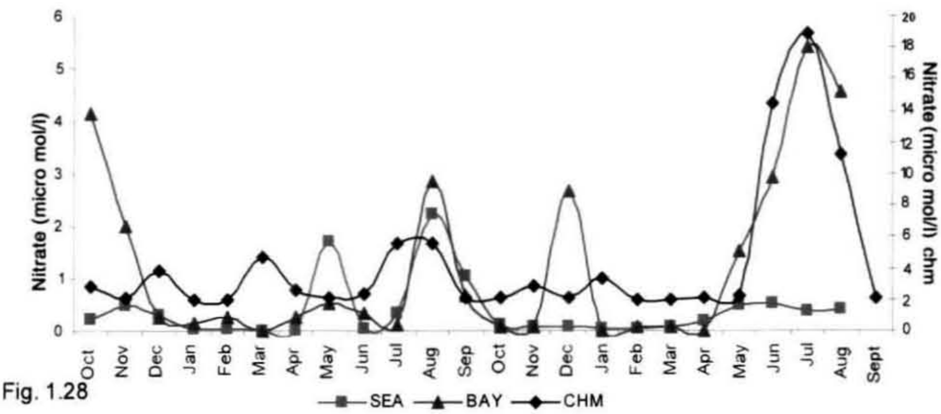


Fig. 1.28

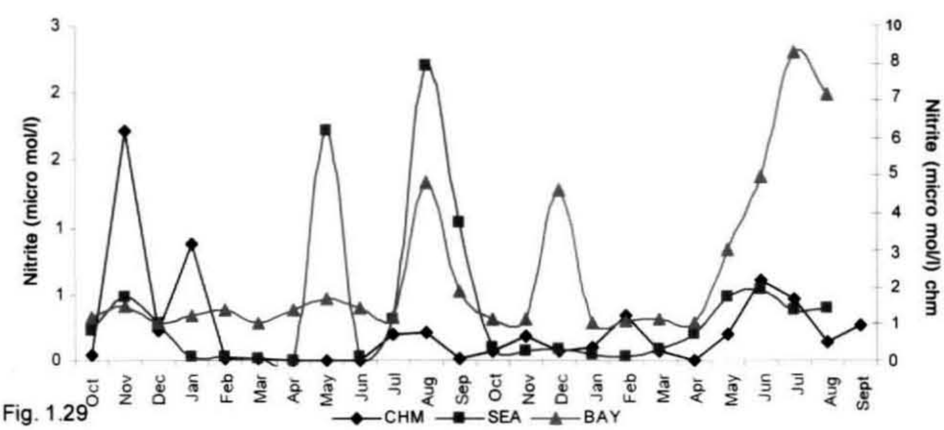


Fig. 1.29

Monthly variation of environmental parameters at Chombala, Vizhinjam bay and Vizhinjam sea
Fig.1.27. Phosphate, 1.28. Nitrate and 1.29. Nitrite

1.3.2.2. VIZHINJAM SEA AND VIZHINJAM BAY

A. METEOROLOGICAL PARAMETERS

The seasonal values and standard deviation of environmental parameters at Vizhinjam bay and sea is presented in Table.1.17a and b.

i. Rainfall

In the first year the highest amount of rainfall of 296 mm was recorded in the month of May followed by October which received the second highest rainfall with 291 mm. In the second year, a high rainfall of 451 mm was recorded in October during the Northeast monsoon followed by 213 mm in June during the southwest monsoon period. The total amount of rainfall received for the region in 2002 was 1460 mm and for 2003, 1350 mm which was lesser than the average annual rainfall of 1690 mm recorded for the region. The southwest monsoon season received 400 mm in 2002 and 441 mm in 2003. The northwest monsoon season of 2002 received heavier rainfall of 727 mm which has higher than 500 mm the previous year and 534 mm in 2003.

ii. Humidity

Humidity percentage varied between a minimum of 71.31 in March and a maximum of 87.88 in August the first year while in the second year it ranged between 69.12% in January to a maximum of 84.4% in August. Seasonally humidity percentage was lowest in the pre-monsoon and maximum in the monsoon season in the first and second years.

B. PHYSICOCHEMICAL PARAMETERS

i. Temperature

The atmospheric temperature over the bay and sea at Vizhinjam was minimum, 27°C in September and highest, 32 °C in the pre-monsoon months of March and April in the first year. In the second year minimum temperature of 26 °C was recorded in November and a maximum of 30°C in March and July. The sea surface temperature in the station at Vizhinjam sea ranged between a minimum value of 27°C in June, August and September and to a maximum of 31°C in March in the first year. In the second year a minimum SST of 26° C was recorded in November and maximum value of 30°C in March. In the bay region, the first year the SST recorded was lower than that noted in the adjacent sea. A minimum value of 25°C was recorded in July and a maximum of 30°C in the months from October to December and from February to April. In the second year it ranged between 26°C in February to 28.5° C recorded in March, June and August

At Vizhinjam sea the seasonal values recorded in the first year were minimum in the monsoon season and maximum in the pre-monsoon season for atmospheric and sea surface temperature. In the second year the temperature was minimum in the post-monsoon season. Maximum atmospheric temperature was for monsoon while the sea surface temperature was highest in pre-monsoon season. In the adjacent bay minimum atmospheric and sea surface temperatures were recorded in the monsoon season the first and in the post-monsoon season the second year. Maximum atmospheric temperature was recorded in the pre-monsoon season both the years. The SST recorded maximum values in both the pre and post-monsoon season in the first year and in the monsoon season in the second year.

ii. Salinity

In the first year of study salinity at sea ranged between a minimum of 31 ppt in November and December to a maximum of 35 ppt in June. In the second year a very low salinity of 25 ppt was recorded in August. A maximum of 36 ppt was recorded in April the same year. Seasonal values for salinity in the sea were lowest in post-monsoon the first year and in monsoon season the second year. Maximum value was in monsoon season the first year while the second year recorded the same and high average value in the pre and post-monsoon season.

In the bay region salinity fluctuated between 31 ppt in September to 35 ppt in June during the first year. In the second year the bay region also recorded a lower value of 25 ppt in August similar to that recorded at sea and a maximum salinity of 35 ppt was registered in the months of January and April. Salinity recorded minimum seasonal value in post-monsoon season the first year and in monsoon the second year. Maximum value in the first year was in pre-monsoon season and in the post-monsoon season in the second year.

iii. pH

The pH values from sea station ranged between 7.62 in March and a maximum of 8.53 in the first year and between 7.86 and 8.47 in the second year. pH values recorded lowest seasonal values in monsoon season both the years and maximum in the pre-monsoon season the first year and in post-monsoon season the second year. In the bay region pH ranged between 7.86 in August to 8.68 in April in the first year. The second year recorded the lowest pH values of 7.92 in June and the highest of 8.45 in January similar to the observations recorded at Vizhinjam sea. pH values recorded minimum seasonal value in the monsoon season and maximum in pre-monsoon seasons in both the years.

iv. Dissolved oxygen

In the first year the dissolved oxygen values at Vizhinjam sea varied between a minimum 2.69 mg l^{-1} in February and maximum 0f 5.42 mg l^{-1} in July. In the second year it varied between 3.53 mg l^{-1} in October and 5.94 mg l^{-1} in May. Seasonal values recorded were lowest during post-monsoon season and highest during monsoon season both the years. The bay region also showed a similar trend in dissolved oxygen values. In the first year a minimum of 1.85 mg l^{-1} was recorded in January and a maximum of 6.08 mg l^{-1} July. In the second year the lowest value of 2.90 mg l^{-1} was observed in October itself but the highest value of 5.51 mg l^{-1} was in March. However a second high value of 5.22 mg l^{-1} was observed in July. Minimum dissolved oxygen value was recorded in post-monsoon season both the years. Maximum value was recorded in monsoon season the first year and in pre-monsoon season the second year.

v. Total suspended solids

In the first year the TSS of the sample from sea ranged between 2.5 to 5 mg l^{-1} in all the months except a high value of 11.40 mg l^{-1} in December 2001and 10.4 in September 2002. In the second year it ranged between a minimum of 2.5 mg l^{-1} observed in November and December 2002, February, March, July and August 2003 to a maximum of 12.5 mg l^{-1} in October 2002. Lowest seasonal values were recorded in pre-monsoon season the first year and in both pre and post-monsoon season in the second year. The highest value of total suspended solids was in post-monsoon season in both the years. In the bay region similar values were recorded and ranged between 2.5 – 14.2 mg l^{-1} during the first year with the highest value in September 2002. Second year it ranged between 2.5 mg l^{-1} observed in November, December 2002, February to April and July 2003 to a maximum of 12.8 mg l^{-1} recorded in Oct 2002. TSS values recorded minimum in the pre-monsoon season and highest in monsoon the first year and in post-monsoon season the second year.

vi. Biological Oxygen Demand

In the first year Biological oxygen demand values at the sea station ranged between 0.5 mg l^{-1} recorded in December and June to August to a maximum of 7 mg l^{-1} in February. In the second year it ranged between 0.5 mg l^{-1} recorded in November, April, July and August to 2.3 mg l^{-1} in June. Seasonally the values were minimum in the monsoon season in the first year and in post-monsoon season the second year. In the bay region BOD in the first year ranged between 0.5 to 8.2 mg l^{-1}, the minimum observed in January and August and the maximum in February. Second year recorded a minimum of 0.5 mg l^{-1} in November February and April and a maximum of 2.6 mg l^{-1} in December.

vii. Nutrients

a. Ammonia

In water samples from sea and bay ammonia was not detected in the months of November and in January and February in the first year. Maximum concentration of 5.2 µmol l^{-1} was recorded in June and 12.40 µmol l^{-1}in August in the bay. In the second year also ammonia was absent in the months from December to April in both the sites but increased to 4.17 μmol l^{-1}in the sea and to 9.18 μmol l^{-1} in the bay in May. Ammonia values recorded the lowest seasonal value in the pre-monsoon months the first year and in the post-monsoon season the second year in the sea. Highest was in the monsoon season in both the years. In the bay seasonal values were lowest in post-monsoon season both the years and maximum in pre-monsoon season the first year and in monsoon season the second year.

b. Phosphate

Phosphate concentration was very low at sea and ranged between zero in November 01 to 2.5 μmol l^{-1} in August the first year. In the second year nil value was observed in November and January and a maximum of 1.312 μmol l^{-1}in April. Seasonal values were minimum in the post-monsoon season both the years and maximum values in the monsoon season the first year and in the pre-monsoon season in the second year. In the first year in the Bay, phosphate was not detected in November. Maximum value 0f 2.5 μmol l^{-1} was recorded in August. In the second year phosphate was absent in October, December and January which increased to a maximum of 0.87 μmol l^{-1} in March. Phosphate values were lowest in pre-monsoon season the first year and in post-monsoon season the second year. Maximum value was recorded in the monsoon season the first year and in pre-monsoon season the second year.

c. Nitrate

Nitrate values showed wide fluctuations at the station. In the first year Nitrate was absent in the sea sample during the months of December, January, March and July. A maximum concentration of 5.16 μmol l^{-1} was recorded in October. In the second year, nitrate concentration ranged between zero in October and February to a maximum of 26.45 μmol l^{-1} in May. Seasonal values were lowest in pre-monsoon the first year and in post-monsoon season the second year. The maximum values recorded were in the post-monsoon season the first year and in monsoon season the second year. Nitrate concentration in the bay region varied from nil value in March to a maximum of 4.17 μmol l^{-1} in October during the first year of observation. In the second year nil values were obtained in January and April and a maximum of 5.39 μmol l^{-1} in July. Seasonal values in the bay region were minimum in the pre-monsoon season both the years. Maximum was in post-monsoon season the first year and in monsoon season the second year.

d. Nitrite

Nitrite concentration at Vizhinjam sea ranged between a minimum of zero in April to a maximum of 2.21 μmol l^{-1} in August . In the second year it ranged between a minimum of 0.03 μmol l^{-1} in February to 0.535 in June. Seasonally the nitrite values were lowest in post-monsoon season both the years and the highest in monsoon season both the years. At Vizhinjam bay region the first year recorded nil values in March and a maximum of 3.82 μmol l^{-1} in August. In the second year it ranged between 0 in April 03 to a maximum of 7.27 μmol l^{-1} in July. A minimum seasonal value of nitrite was in post-monsoon season and the highest in monsoon season both the years.

C. ENVIRONMENTAL CORRELATIONS

At Vizhinjam AT showed positive correlation with SST at both sea and bay (r=0.793 and 0.733). Dissolved oxygen showed positive correlation with rainfall (r=0.565) in the sea and negative with SST (r=0.525). Humidity showed positive correlation with rainfall (0.565) at the station. In the sea it was correlated positively with phosphate (r=0.45), negatively with SST (r=0.444). In the bay it related negatively with pH (r=0.628) and positively with nitrate (r=0.444) in the bay. In both the stations ammonia was positively correlated with nitrate(r=0.447 and 0.453) and nitrite (0.439 and 0.585). Ammonia also showed positive correlation with SST (r=0.499) and humidity (r=0.517) in the sea. Nitrate showed positive correlation with nitrite (r=0.851) and negative with salinity (r=0.607) in the sea. Nitrite correlated positively with Phosphate (r=0.556) and negatively with salinity (0.684) in the bay. The results of the Pearson correlation analysis between environmental and biological parameters is presented in Table.1.18.

Table.1.17a. Seasonal values and standard deviation of environmental parameters at Vizhinjam bay for the period from October 2001 to August 2003.

Month	Humidity	Rainfall	Temp		Salinity	pH	DO	TSS	BOD	Nutrients)			
			At.T	SST						NH_3	PO_4	No_3	No_2
	%	mm	(°C)		ppt		mg l^1			(µ mol $l^{-1)}$			
Post M I													
Average	79.6	125	30	29.5	32.4	8.02	2.7	5	0.88	0.34	0.35	1.65	0.22
Std dev	0.6	135.9	0.8	1	0.5	0.08	0.61	0	0.25	0.48	0.37	1.88	0.19
Pre M I													
Average	75.6	98	30.8	29.5	33.3	8.31	3.57	4.1	2.75	4.57	0.27	0.27	0.36
Std dev	5.1	133	1	1	1	0.26	0.63	1.93	3.63	4.34	0.14	0.21	0.29
Monsoon I													
Average	85.3	100	27.8	27	33	7.99	4.5	5.93	1.1	4.25	1.35	0.99	1.33
Std dev	2.9	85.4	1	1.8	1.8	0.14	1.24	5.6	0.94	5.48	0.89	1.25	1.69
Post M II													
Average	77.4	174.3	27	27.4	34	8.2	4.28	7.86	1.78	0.35	0.07	0.71	0.95
Std dev	7	217.9	0.8	0.8	0.8	0.18	0.94	5.04	0.98	0.68	0.14	1.3	1.75
Pre M II													
Average	77	110.3	28.6	27.6	33.8	8.22	4.89	2.93	1.03	2.3	0.58	0.41	0.56
Std dev	3.1	51.3	2.6	1.1	1.2	0.13	0.52	0.85	0.67	4.59	0.35	0.73	0.98
Monsoon II													
Average	83.7	146.7	28	28	29	8.01	4.67	6.37	1.1	6.97	0.16	4.3	5.8
Std dev	1	60.1	1	0.9	3.5	0.11	0.72	4.37	1.04	0.5	0.02	1.25	1.69

Table.1.17b. Seasonal values and standard deviation of environmental parameters at Vizhinjam bay for the period from October 2001 to August 2003.

Month	Humidity	Rainfall	Temp		Salinity	pH	DO	TSS	BOD	Nutrients)			
			At.T	SST						NH_3	PO_4	No_3	No_2
	%	mm	(°C)		ppt		mg/l	mg/l		(µ mol/l			
Post M I													
Average	79.6	125	30.25	29.75	31.9	8.07	2.98	5.98	1.9	0.83	0.2	1.79	0.25
Std dev	0.6	135.9	0.5	0.5	1.2	0.08	0.28	3.8	2.15	1.3	0.27	2.44	0.18
Pre M I													
Average	75.6	98	31	29.75	32.8	8.17	3.78	3.13	2.43	0.67	0.24	0.14	0.44
Std dev	5.1	133	1.41	1.26	1	0.39	0.9	1.25	3.05	0.55	0.14	0.15	0.85
Monsoon I													
Average	85.3	100	28.75	27.25	33.8	7.96	4.41	4.73	0.83	3.39	1.3	0.83	0.9
Std dev	2.9	85.4	1.26	0.5	1	0.21	0.73	3.81	0.65	2.04	0.87	1.35	0.97
Post M II													
Average	77.4	174.3	27	27	34.5	8.3	4.47	5.68	1.03	0.06	0.16	0.69	0.07
Std dev	7	217.9	0.82	0.82	0.6	0.12	0.75	4.72	0.48	0.11	0.33	1.29	0.02
Pre M II													
Average	77	110.3	28.15	28.5	34.5	8.19	4.68	3.43	1.38	1.04	0.72	7.38	0.2
Std dev	3.1	51.3	1.3	1	1.3	0.19	0.86	1.08	0.6	2.09	0.45	12.79	0.2
Monsoon II													
Average	83.7	146.7	29.33	27.33	30	7.99	4.79	3.43	1.1	2.28	0.5	17.33	0.44
Std dev	1	60.1	0.58	0.58	5	0.12	0.25	1.62	1.04	1.2	0.05	3.69	0.08

Table.1.18. Significant correlation values between environmental parameters at Vizhinjam

	SEA AT.T	BAY AT.T	SEA DO	BAY DO	SEA COD	SEA HUM	BAY HUM	SEA AMM	BAY AMM	BAY Nitrate	SEA NITRITE
NITRATE							0.444*	0.447*	0.453*		
NITRITE								0.439*	0.585**	0.851**	
PHOSHATE						0.45**					0.556**
SST	0.793**	0.733**		-0.525*		-0.444*		0.499*			
pH							-0.628**				
HUMIDITY								0.517*			
RAINFALL			0.565**			0.565**	0.565**				
SALINITY										-0.667**	-0.684**

1.4. DISCUSSION

Phytoplankton population and growth depend on several environmental factors which show temporal and seasonal variations. The major factors affecting phytoplankton production are degree of irradiance, spectral composition of light, water temperature and concentration of major nutrients, which in turn are dependent on several other abiotic and biotic factors (Svedrup et al., 1942; Raymont, 1980). The phytoplankton community structure and distribution of the sites under study and the major factors influencing these are discussed below.

The climate of the west coast of India is dominated by two monsoons, the southwest monsoon from May/June to September and the northeast monsoon starting from November/ December and continuing upto March, with short transition periods characterised by hot dry weather in between (Subrahmanyan, 1959a). Many studies have shown that an increase in phytoplankton density occurs in the coastal waters of India usually in the monsoon and post-monsoon months (Subrahmanyan, 1959a; Devassy and Bhattathiri, 1974; Gopinathan *et al.*, 1974), associated with lowering of water temperatures and salinity and an increase in nutrients, all the three associated with monsoonal rainfall in the region. A more recent study by Sreekumaran *et al.* (1992) on the occurrence of phytoplankton blooms along the west coast of India points out that the episodic introduction of nutrients during June to September through river runoff and coastal upwelling is the major reason for phytoplankton blooms during the monsoon and post-monsoon periods. Pillai *et al.* (2000) pointed out that, studies on phytoplankton characteristics along the Indian coast over the years have shown that the seasonal changes brought in through pre-monsoon, monsoon and post-monsoon phenomena, along with resultant oceanographic changes influence the overall productivity of the Indian coastal waters significantly. In the present study also, an increase in phytoplankton density was noticed just after a period of intense rainfall. The positive correlations of rainfall and humidity with productivity, phytoplankton density and with biomass were also obtained. These are comparable with the observations of Devassy and Bhattathiri (1974), Gopinathan *et al.* (1974), and Sreekumaran *et al.* (1992).

The close similarity in the curves of atmospheric temperature and sea surface temperature and the highly significant positive correlation between the two at both the sites reveal that sea surface temperature is considerably influenced by atmospheric temperature. Wide fluctuations in temperature were not observed at both the sites and was within the range reported for the coastal waters by Kumaran and Rao (1975); Gowda *et al.* (2001, 2002); Balachandran *et al.* (1989); Pillai (1991); Marichamy *et al.* (1985) and Gopinathan and Rodrigo (1991). At Chombala, both atmospheric and sea surface temperature exhibited a bimodal oscillation with two maxima and two minima corresponding to the two dry seasons and to the two cool seasons of the region. The peaks were observed in late pre-monsoon months and in September-November. Such a similar temperature pattern was not recorded at Vizhinjam. Both the stations at Vizhinjam exhibited intermittent increase and decrease between the months. Rani and Kumar (1984) noted maximum temperature as 30.3° C in May and minimum as 24.5 ° C in August at Vizhinjam and Dharmaraj *et al.* (1986) noted that the sea surface temperature varied between 24.8 °C in September to 30.5 ° C in April and atmospheric temperature between minimum of 21.6°C in June to 30.1°C in January in Vizhinjam bay. In the present study temperature never fell below 26°C in any of the stations. But lower temperature between 24-25°C was noted by Subrahmanyan (1959b), Balachandran *et al.* (1989) and Gowda *et al.* (2001) for coastal waters. In addition to the cool monsoon showers, the lower temperature in the surface waters during south west monsoon months along the south west coast has also been attributed to the upwelling of cool nutrient rich bottom waters to the surface. Ramamirtham and Jayraman (1963); Pillai *et al.* (1980, 2000) and Banse (1996) have reported upwelling extending from early monsoon upto September- October in the region. Pillai *et al.* (2000) identified the region between 8°30' off Trivandrum and 11°30' N off Calicut near the coast as regions of intense upwelling. The negative correlation of sea surface temperature with rainfall in all the stations indicates that a major reason for reduced temperature is rainfall along with upwelling. At Vizhinjam the high saline and low temperature waters at the surface in the second year of study is also indicative of upwelling.

The salinity values in all the three stations did not show any major fluctuations. Higher values of salinities are recorded during periods when air and water temperatures were high, wind force greater and humidity low (Subrahmanyan, 1959b). Salinity showed a unimodal oscillation with minimum in monsoon season and maximum during pre-monsoon seasons at Chombala. Salinity was high in the pre-monsoon period characterised by high temperature, low humidity and rainfall. Salinity values at both Vizhinjam sea and bay showed low values during the post-monsoon season coinciding with the heavy rainfall. Low average values were recorded in monsoon in the second year. A very low salinity of 25 ppt was observed in August 2003 which was lower than that observed by Dharmaraj *et al.* (1986) for the bay region who recorded a minimum of 27.9 ppt in the Bay in May and maximum in December (36.2 ppt). But Rani and Kumar (1984) did not record any such wide fluctuations in salinity for the region. Salinity has shown a negative correlation with humidity at Chombala which supports the lowering of salinity in the monsoon season. It has also shown a negative correlation with ammonia and nitrite in the station which indicates that concentration of these nutrients increases in low saline periods which are the rainy months in this case.

The pH values fell within the normal range at all the stations. Variation in pH is governed by a number of factors such as photosynthetic release of O_2 and Co_2, respiratory processes of animals and plants, monsoonal precipitation and resultant dynamics of oxygen etc (Dharmaraj *et al.,* 1986). It is well documented that dense population of phytoplankton can raise the pH of natural waters by actively removing Co_2 from the water column by photosynthesis. Comparatively lower pH was noticed during the bloom of *Chattonella marina* at Chombala. The haemolytic chemical substances secreted by the algae might be the reason for this low pH. The range of pH noticed at Vizhinjam bay and sea was wider than that reported by Dharmaraj *et al.,* (1986).

The dissolved oxygen values did not show any similarity in pattern between the stations. The solubility of oxygen is found to increase with decreasing temperature and salinity. It is usually noted that the phytoplankton population in its initial exponential phase of growth results in increased dissolved oxygen content in the surface waters which even exceeds the saturation point due to the high level of photosynthesis. The dissolved oxygen content also increases due to increased agitation of water during monsoon showers The dissolved oxygen value at Chombala showed a very high value of 11.7 mg l^{-1} in October when the productivity was also high, similar to high values noticed during increased phytoplankton production by Kumaran and Rao (1975), Ganapathy and Raman (1979). Also, the northeast monsoon characterised by heavy winds must have caused increased agitation and mixing leading to the increased values noticed in this month. Very low value was noticed in the months of September both the years at Chombala, coinciding with a heavy bloom of *Chattonella marina.* Factors such as high rate of oxygen consumption throughout day and night by the increased number of phytoplankton cells, bacterial development following phytoplankton development which increases the oxygen consumption and decomposition of dead and decaying organic matter which consume considerable quantities of oxygen tend to lower the oxygen content of the water during bloom periods (Subrahmanyan, 1959b; Devassy *et al.,* 1978; Venugopal *et al.* 1979; Satpathy and Nair., 1996).

The total suspended solid content in Chombala was higher when compared to that at Vizhinjam sea and bay. High average values for TSS were recorded during the monsoon season at Chombala. Apart from monsoon hikes, unusually high values were recorded in certain months during the pre-monsoon period and incidentally these were coincident with blooming of phytoplankton. Such incidences were noted in May in both the years and in September 2003 related to bloom of *Coscinodiscus asteromphalus, C. excentricus and Chattonella marina* respectively. A high suspended solid content was noted during the bloom of *Asterionella japonica* by Satpathy and Nair (1996) at Vizag. High TSS value was also noted during the post-monsoon months at Vizhinjam sea during which the cyanophycean algae *Trichodesmium erythraeum* was dominant in the phytoplankton sample. TSS values in the bay region fell within a narrow range except a high value noted in September to October 2002 and in August 2003. A high concentration of the diatom *Chaeoceros curvisetus* was noticed in phytoplankton sample in both the months and that of *Noctiluca scintillans* in August 2003. The significant correlation shown by TSS with productivity values at both the stations and with total phytoplankton density at Vizhinjam sea strongly supports the fact that increased phytoplankton density might be one of the reason for increased suspended solid content in coastal waters. Dharmaraj *et al. (*1986) has inferred that apart from the land drainage with enormous quantities of suspended sediment load, monsoonal winds which stir up the bottom, possible upwelling during the time, greater agitation of water masses and luxuriant growth of phytoplankton during the diminishing stages of monsoon would add to causes of low transparency and high turbidity during the monsoon period. TSS content can thus be used as an indicator of bloom conditions in certain circumstances.

Apart from the above factors the seasonal and regional variation of phytoplankton growth are dependent upto a major extent on the rates of regeneration of nutrients and their return to the water column by physical, chemical as well as biological processes. The major nutrients which influence phytoplankton production are nitrates and phosphates (Raymont, 1980). In the temperate regions, the oscillation of phosphate is a bimodal with a pronounced winter maximum and a minor one in summer. In the tropics there are no well defined seasons and similar major fluctuations are not observed. Most of the studies on coastal hydrological variations have observed higher values either during monsoon and post-monsoon season. Subrahmanyan (1959b) observed peak values in the southwest monsoon season and minimum in the northeast monsoon along the Calicut coast, with concentration ranging between a minimum of 0.13 in January to a maximum of 1.68 µg at/l in August. Balachandran *et al.* (1989) recorded high values both during monsoon and post-monsoon season along the coastal waters of Cochin. Comparatively higher values were recorded by Rani and Vasantha (1984) in the Vizhinjam region. Dharmaraj *et al.* (1986) in his study at the same region also noted the peak values in the post-monsoon season and the minimum in the pre-monsoon months. Along the east coast however peaks of phosphate were recorded in the pre-monsoon season and preceded maximum phytoplankton production. Lower values of phosphate coinciding with peak phytoplankton production was also observed by Qasim, 1980; Murugan and Ayyakkanu, 1993). Marichamy *et al.* (1985) noted three peaks of phosphate between the post-monsoon and pre-monsoon periods and noted that all the three peaks preceded peak periods of phytoplankton production. Vijayakumaran *et al.* (1996) also noted peak values in the pre-monsoon season. The values recorded was 5.75 µg at/l in April, which was the highest reported along the coast.

In the present study the concentration of phosphate at both Chombala and Vizhinjam fell within the range recorded in the above works. On an average, the concentration of phosphate at Vizhinjam was lower than that at Chombala. Gopinathan (2001) identified the south Arabian sea to be the richest in nutrient and recorded the highest concentration of 2.62 at Kannur and 1.77 µg at/l at Calicut. At Chombala high values were recorded in the southwest monsoon months. Intermittent increase was observed in some months usually coinciding with peak phytoplankton production. The positive correlation of phosphate with productivity and chlorophyll pigments indicates it to be a major nutrient influencing the production at this station. Values above 3µg at/l were recorded at Chombala and Ketchum (1967) observes that values higher than 3 is indicative of eutrophied conditions. At Vizhinjam peak values preceded months of high phytoplankton production. The high values of phosphate during monsoon have been suggested to be due to land drainage by Dharmaraj *et al.* (1986). Complete depletion of the nutrients along the coast was not recorded any of the studies at any time which has been suggested to be due to phosphate regenerative activity of muds as indicated by Reddy and Sankaranarayana (1972) and exchange of nutrients with sediments and underlying water as suggested by Pomeroy *et al.* (1965).

Subrahmanyan (1959b) has suggested that considerable quantity of phosphate is locked up in the seabottom which goes into the solution during the stormy weather of the south west monsoon season. Activity of phosphate solubilising bacteria has also been suggested as major reason (Dharmaraj *et al.*, 1986). Upwelling along this coast in this season also increased the surface concentration of this nutrient (Vijayakumaran *et al.*, 1990). But in the present study complete depletion of phosphate was recorded once at Chombala and in many of the post-monsoon months at Vizhinjam. This indicates that phosphate is a phytoplankton production limiting factor at Vizhinjam. Any addition of phosphate to the system might trigger a bloom.

The concentration of nitrate recorded peak values in different seasons in the earlier studies. Subrahmanyan (1959b) recorded the highest value in the pre-monsoon months of April or May or in the early part of the southwest monsoon. Rani and Vasantha (1984) recorded high values in the Vizhinjam sea than at bay. The maximum values recorded by Dharmaraj *et al.* (1986) were higher and varied between the 1.86 in April and 8.05 µg at/l in September. Along the Mangalore coast Gowda *et al.* (2001), recorded the lowest values in the pre and post-monsoon months, ranging between 1.1 and 7.28 µg at/l. Similar seasonal peaks were observed by Selvaraj *et al.* (2003) with peak in monsoon season in the surf zone at Cochin and minimum in the post-monsoon season. Along the east coast, peak production was observed by Gopinathan and Rodrigo (1991) in March-May and in July and Ocotober. Vijayakumar *et al.*(1996) also observed the peak values in the pre-monsoon season off the Vizag coast.

At Chombala, the nitrate concentration increased with increased rainfall and drainage during the monsoon which was utilised by the high standing crop of phytoplankton which reduced the concentration of this nutrient to negligible values during the post-monsoon months. Menzel and Spaeth (1962) reported that ammonia concentration increased considerably with rainfall and oxidation of it subsequently to nitrate and nitrite increase their levels during monsoon. Subrahmanyan (1959b) also suggested monsoonal rains and resultant land run off as the main reasons for increased values of nitrate, which is supplemented by oxidation of organic matter, nitrogen fixation by blue green algae and bacteria and excretion by plankton (Dharmarj *et al.,* 1986). The low values during pre-monsoon have been attributed due to biological uptake. This supports the very early finding by that river inflow during monsoon season as the main reason for the increased nutrient content of coastal waters. Upwelling and release of nutrients locked up in sediments during the monsoon have been indicated as the reason for increased concentration. The bay recorded low values through out the year when compared to that at sea. This indicates that the increased concentration of the nutrient at Vizhinjam was not due mainly to rains and resulting land drainage but might be due to upwelling. Steep changes in concentration were recorded at all the stations, as observed for Cochin backwaters by Qasim (1973), which suggest that it is utilised as soon as it is replenished to the system. A positive correlation of nitrate with rainfall and humidity and a negative one with rainfall and a negative correlation of nitrate and nitrite with salinity indicate that high concentration of these nutrients are associated with monsoon and related factors along the coast.

Compared to nitrate and phosphate the concentration of nitrite is very low in the waters along the Indian coast. The highest recorded was 2.07µg at/l by Vijayakumaran *et al.* (1996) along the Vizag coast. Rani and Vasantha (1984) recorded minimum of 0.12 in February and a maximum of 0.52 µg at/l in August in the bay. At sea lowest concentration of 0.11 was noticed in November and highest of 0.50µg at/l in March. Dharmaraj *et al.* (1986) noted that even though the concentration was low at all times there was no complete depletion at any time as the assimilation of nitrate by marine phytoplankton is accompanied by the extracellular production of nitrite. Balachandran *et al.* (2003) recorded two peaks one in the pre-monsoon season and the second during June and July at Cochin. In the same region Selvaraj *et al.* (2003) also noted high values in the pre-monsoon season. Both the workers suggest low values in other months due to full utilisation by phytoplankton. Along the east coast, Marichamy *et al.* (1985) recorded low values in May-July and in September in the inshore waters of Tuticorin. Gopinathan and Rodrigo (1991) also reported very low values in the same region with slight increase only in April-June and in February-May. Both the authors confirm the observations made by other workers that low concentration is due to rapid utilisation by phytoplankton. Marichamy *et al.* (1985) also adds that the action of denitrifying bacteria as a reason for these low values. In the present study, the nitrite content at Vizhinjam sea and Chombala were low and was within the limits observed in the above mentioned studies.

The concentration of ammonia was very low when compared to that at Chombala. It did not show any distinct seasonal pattern at Chombala and Vizhinjam. A high value of ammonia suggests an increased input of nutrients from terrigenous sources. In the bay region ammonia was absent in most of the sampled months. Peaks in May and August coincided with rainfall. Discharge of land drainage into the bay seems to be a major contributor as suggested by Dharmaraj *et al.* (1986).

Primary productivity is the main criterion for assessing the relative fertility of a particular region. Along with this, photosynthetic pigments are the index of phytoplankton production of an area. The biological productivity of the coastal waters are dependent to a major extent on the distribution of photosynthetic pigments in the euphotic zone (Gopinathan *et al.*, 2001). Thus an estimation of primary productivity along with the estimation of photosynthetic pigments gives a clear picture of the fertility of these waters. The temperate oceans which are characterised by distinct seasons exhibit two distinct peaks in phytoplankton production the major one in spring and the minor in autumn. The tropical seas characterised by a year long stratification due to the intense sunlight t similar distinct peaks in production as those of temperate seas are not observed (Raymont, 1980). According to Qasim (1979) and Radhakrishna *et al.* (1978) the west coast of India is an area having wide temporal and spatial fluctuation in productivity. Earlier studies along Calicut coast (Subarahmanyan, 1959b) off Alleppey (Radahakrishna, 1969), in Cochin backwater (Gopinathan, 1974) have all shown that the phytoplankton production is maximum during southwest monsoon. Dehadri and Bhargava (1972) noted that along the coastal waters from Goa to Bombay Chl *a* maximum was in the post-monsoon months between November to January where as Varshney *et al.* (1983) who studied the primary productivity in the nearshore waters off Maharastra have also shown maximum Chl *a* in the south west monsoon months from July to August itself. But Marichamy *et al.* (1985) noted the peak of production in October-December followed by two minor peaks in January- February, June-August along the east coast. Satyanarayana (1994) noted that in the coastal waters off Vizag highest peak was in pre-monsoon and attributes this peak in pre-monsoon due to high phytoplankton resulting from dinoflagellate maximum and upwelling of nutrient rich waters. A comparison of the primary productivity of the coastal waters from Dabohl along west coast to Tuticorin along east coast was made by Qasim *et al.* (1978) who found it to be varying between 0.85 to 6.75 mgC/m^3/hr while the chlorophyll *a* concentration varied between 0.05 to 4.18 mg C/m^3. Rani and Vasantha (1984) have estimated that the gross productivity of Vizhinjam bay varied between 114 to 672 mg C/m^3/ day and at sea between 185 to 739 mg c/m^3/day with the peak production coinciding with the two monsoons. The higher values obtained for Rani and Vasantha (1984) in the bay was in June and November. Off Mangalore coast Nair and Pillai (1983) noted maximum production in the pre-monsoon and monsoon which was supported by Krishnakumari *et al.* (2002) who found that it fluctuated between 0.02 and 7396 mgC/m^2/day. Manjappa (1987) reported Chl *a* values between 0.14 and 2.58 mg/m^3 with the peak in Jan-March. Chl *b* showed a similar peak with a maximum of 5.27 mg/m^3. Linghadal (2003) in the same region recorded peaks of Chl *a* in October –December and minor peaks in February –March with a peak value of 30.85 mg/m^3. Tiwari and Nair (1998) noted high Chl *a* of 6.4 mg/m^3 in Dharmatar creek coinciding with *Skeletonema costatum* bloom. Balachandran *et al.* (1989) noted three peaks for Chl *a* with the highest peak of 3.6 mg/m^3 in

March and lowest in May (0.24). Gopinathan and Rodrigo (1991) noted high productivity of 1600 $mgC/m^3/day$ in April and low of 114 $mgC/m^3/day$ in November. Vijayakaumaran *et al.* (1996) noted high production in the pre-monsoon months between March and April with maximum recorded value of 226 $mgC/m^3/day$. Gopinathan *et al.* (2001) who studied the distribution of Chl *a* and *b* in the eastern Arabian sea noted the highest Chl *a* value of 8.28 mg/m^3 off Cape comorin in the post-monsoon. Selvaraj (2003) noted highest production in Fort Cochin during pre-monsoon (1.029 $gc/m^3/day$).

Comparitively high productive values were obtained at all the three stations than that recorded in the above works. Qasim (1978) has reported that the region between Calicut and Karwar as the most productive zone along the west coast followed by the area between Calicut and Cochin. At Chombala the highest productivity values was observed in the late monsoon months and in the early pre-monsoon periods while at Vizhinjam bay and sea highest value of gross productivity was observed in the southwest monsoon months. In the sea gross productivity was high in the same period. In the present study higher values for both gross and net productivity than that obtained by Rani and Vasantha (1984) for the region were obtained. Nil values were observed in February and April at sea which indicates the unhealthy condition of the site during these months. Net productivity of a region becomes zero when respiration exceeds photosynthesis. Similar observations were made by De *et al.* (1994) in Hoogly estuary and they inferred that the phytoplankton community of the system was under stress mainly due to pollution and climatic changes. High value of productivity always coincided with the occurrence of bloom or with a general increase in phytoplankton biomass as obvious from the increased pigment values during the months. A significant positive correlation of productivity with the total phytoplankton count and with the major pigment Chlorophyll *a* also supports this. The highest value of productivity noticed at Chombala coincided with the bloom of *Chattonella marina* in the region. Similarly high values were noticed in October 2001 when the diatom *Coscinodiscus asteromphalus* was present in high densities in the sample. At Vizhinjam sea and bay region also the highest productive values noticed in October 2002 coinciding with a heavy cell density of *Chaetcceros curvisetus* in the region. In September 2002 the diatom *Coscinodiscus* was present in increased concentration in the sample which resulted in high productive values. Even if higher cell densities than that in September 2002 were noticed in other months such high production values were not observed. This may be because being a comparatively larger diatom the amount of Chl *a* present in *Coscinodiscus spp* is higher and hence rate of production was also higher for this diatom (Subhrahmanyan, 1959a). The zero productivity values indicate that the organic material produced in the system is consumed or removed from the system at the same rate as a result of which there is no net production. The highest amount of Chlorophyll *a* and c was obtained during the bloom of *Chattonella marina* in September 2003. The chlorophyll values observed at Vizhinjam station was very low when compared to that of Chombala. High concentration of Chl *a* and carotenoids was recorded at Vizhinjam sea and bay when the diatoms Coscinodiscus and C. curvisetus were present in increased concentrations while high Chl *b* and Chl *c* concentrations were observed in the bay when the diatom *Ditylum sol* was present in increased concentration. High value of Chl *a* has been reported by Qasim and Reddy (1967) off Cochin (85.3 mg/m^3) in August and September and they have attributed such high values to interference of phaeopigments and other degraded chlorophyll products. Chl *a, c* and carotenoids showed a high positive correlation with productivity at Chombala and with Chl *a* and carotenoids at Vizhinjam bay. According to Subrahmnayan (1959a) a direct proportional relationship is not observed in many instances because the size of the cell and the pigment content of the individual phytoplankton cells vary considerably. Thus even if in certain months phytoplankton cell density may be higher the pigment concentration is not comparatively higher. This becomes especially clear in the case of *Coscinodiscus*. In months where this algae is dominant increased chlorophyll values were recorded even if the cell densities were lesser.

Qasim *et al.* (1978) Rani and Vasantha (1984) Satyanarayana (1994) observed a strong correlation between primary productivity inorganic phosphate. Pillai *et al.* (1975) noted negative relation between primary production and phosphate upto 100m in the coastal waters of Arabian sea and negative correlation with Chl *a* during post-monsoon. Qasim *et al.* (1978) noted a negative correlation between Chl *a* and nitrite suggesting that nitrite was a limiting nutrient and phosphate was present in excess. Marichamy *et al.* (1985) Balachandran *et al.* (1989) noted negative correlation between productivity with both phosphate and nitrate. Tiwari and Nair (1998) noted high positive correlation between Chl *a* and phytoplankton count. El Gindy and Dorgam (1992) noted positive correlation between phytoplankton production and nitrate, phosphate and ammonia in the Arabian gulf. Gopinathan *et al.* (2001) noted a negative correlation between chlorophyll *a* and nutrients in the south part pf the Arabian sea, the region which includes the sites under study and concludes that nutrients were fully utilized by phytoplankton during their growth. A positive correlation between the two was noted in the north which indicates that in this region the nutrients were only partially utilized and was present in excess needed for phytoplankton growth. In the present study net productivity showed a positive correlation with ammonia in the bay and with phosphate at Chombala which indicates it to be the major nutrient controlling the productivity of these regions.

It was observed that two most diverse phytoplankton groups diatoms and dinoflagellates were important in terms of both species diversity and density at both the sites. As seen by the correlation results the diversity at all the stations are mainly due to these two major groups of phytoplankton. In addition to this blue green algae was recorded from samples at both the sites but more frequently from Vizhinjam sea and a rapidophyte from Chombala. The dominance of diatoms in the coastal waters of Calicut and the regular occurrence of the rapidophyte after southwest monsoon was observed by Subrahmanyan and Sarma (1960). A study on phytoplankton of Cochin backwaters by Gopinathan (1974) and Kumaran and Rao (1975) recorded the dominance of diatoms in the region. A study by Selvaraj *et al.* (2003) later in the period between 2001 and 2002 in the same region noted that 99% of the total phytoplankton species were diatoms and attributes this reduction in species diversity to changes in climatic conditions and to a decrease in water quality of the region, mainly due to urbanization and industrial pollution. Diatom dominance (79%) has also been noted by Tiwari and Vijayalakshmi (1998), Rajgopal (1981) and by Gowda *et al.* (2001) in the west coast and along the east coast by Raman and Prakash (1989), Murugan and Ayyakkannu (1993), De *et al.*(1994) and Gowda and Panigrahi (1996). Contrary to this Geetha and Kondalarao (2004) recorded a slight dominace in species numbers by dinoflagellates (131) than diatoms (111) in northeast Bay of Bengal. The increase in dinoflagellate diversity was contributed by the two genera *Ceratium* and *Peridinium.*

The dominance of diatoms was more than 80% at Chombala and slightly lesser at Vizhinjam. A higher number of diatoms were recorded in the sea than at the Bay. The decrease was mainly because there was a dominant presence of dinoflagellates at Vizhinjam the diversity being controlled by the two genera *Ceratium* and *Peridinium.* Similar observation was made by Geetha and Kondalarao (2004) who observed that the dinoflagellate diversity along the east coast of India was controlled by the same two genera. The dinoflagellates *P. micans* and *D.caudata* was also represented in the phytoplankton community in most of the sampled months. *D. caudata* is suspected to cause DSP and the distribution and dynamics of this species will be discussed in detail in the next chapter. The cyanophycean algae *Trichodesmium sp* was also present in the sample from Vizhinjam more at sea than at bay. Cyanophyceae usually increases in numbers most often during the warmer months of the year. Its preference for increased temperatures has been reported in the Indian waters by Subrahmanyan (1959b), Ramamurhty *et* *al.* (1972), Devassy *et al.* (1978). A positive correlation of *Trichodesmium spp* with atmospheric temperature was obtained in the present study also.

It was observed that diatoms which are the dominant members of the phytoplankton community start increasing with the onset of monsoonal rains which brings in large quantities of nutrients into the system by land runoff and coastal upwelling. A decrease in salinity and temperature which follows monsoon showers is also thought to favour the spurt of phytoplankton population dominated by diatoms by many workers (Qasim *et al.*,1972; Gopinathan, 1974). The dinoflagellates were found to increase with increasing temperature stratification from September onwards. Similar observations were made by Subrahmanyan and Sharma, 1960; Devassy and Bhattahiri, 1974 and Gowda *et al.*, 2001. *C. marina*, a flagellate also blooms regularly along the coast during the post-monsoon months which was also noticed by Jacob and Menon (1948) Subrahmanyan (1959), Subrhramanyan and Sharma (1960).

Quantitatve studies on phytoplankton has shown that phytoplankton increase in cell density mostly during the pre-monsoon and post-monsoon periods and generally is less dense during the monsoon period (Subrahmanyan, 1959b; Ganapathy and Rao, 1953; Dehadri and Bhargava, 1972; Kumaran and Rao, 1975; Qasim, 1980; Murugan and Ayyakkannu, 1993). It was observed that whenever favourable condition arise they bloom leading to total increase in phytoplankton density during various times of the year. Tiwari and Nair (1998) who studied the ecology of phytoplankton along the Bombay coast report a bimodal pattern with population maximum during September to October and secondary one in April. Gowda *et al.* (2001) noticed a trimodal peak for phytoplankton density in Netravathi estuary in the months of May, June/July and in November/December. He observed that peak phytoplankton production coincides with periods of increased temperature and light conditions and with increased nutrient concentration. Selvaraj *et al.* (2003) observed a trimodal pattern with peaks in October, January and April in the inshore waters off Cochin. Increased phytoplankton density was observed at Chombala in the pre-monsoon months from March to May. The post-monsoon months of September, both the years recorded high density due to the bloom of *C. marina* in the region. The increase in phytoplankton production in these months were dependent on increased density of one or two species. In March it was due to *Thalassiothrix frauenfeldii, Thalassionema nitzschioides* in April and due to *Pleurosigma normanii* in May.

At Vizhinjam bay and sea the post-monsoon season from August to October recorded high densities of phytoplankton. The sea region recorded minor pulses of production in

December and May due to high cell density of *Chaetoceros curvisetus* The high density in August, September and October was also mainly due to this diatom. Qualitative analysis also revealed the dominance of this diatom in most of the months. Thus bulk of the phytoplankton production seemed to be dominated by this algae. In August 2002 and 2003 the diatom *Fragilaria oceanica* was present in high densities. In the bay region incidences of increased production occurred in December due to increased density of *T. frauenfeldii,* in February due to *S. costatum*, in May by *Navicula spp* and in August 2002 due to *C.curvisetus* and *F.oceanica*. The higher density of phytoplankton in the bay when compared to that of sea might be due to concentration of the phytoplankton in the enclosed bay region by wind and currents. The constant replenishment of nutrients either from land drainage or from the bottom could have catalysed this.

Both qualitative and quantitative analysis revealed that major part of phytoplankton production was contributed by a few species in the region of which diatoms dominates. Subrahmanyan and Sarma (1960) prepared a list of 37 phyoplankton species as dominant forms which constitute the bulk of the flora during different months of the year. Of these the diatoms *Chaetoceros brevis, C.contortum, C.lauderi, C.pelagicus* and the dinoflagellate *Glenodinium lenticula* were not recorded in the present investigation. The only cyanophycean which made a dominant presence was recorded as *T.erythraeum* which was recorded in the present study also. Kumaran and Rao (1975) found that the phytoplankton dominance was contributed mainly by *S.costatum, N. closterium* and *Coscinodiscus* in Cochin backwaters. Rajgopal (1981) recorded the diatoms *Coscinodiscus, Navicula, Thalassiosira, Pleurosigma* and the dinoflagellates *Peridinium, Dinophysis* and *Noctiluca* as the dominant forms. Dominance of the diatoms *Nitzschia* in North west Bay of Bengal (Prakash and Sharma 1992), *Coscinodiscus* and *Chaetoceros* in Cuddalore and Uppanar backwaters (Muruagan and Ayyakkannu, 1993) and *Coscinodiscus* in Hoogly estuary (De *et al.*, 1994) and in the coastal waters of the east coast of India (Gowda and Panigrahi, 1996) has been noted. Study by Prakash and Sharma (1992) in the northwest Bay of Bengal showed that the blue green alge *T.erythraeum* was the major contributor of phytoplankton followed by *N.seriata, R. cylindrus, T.longissima, E.zodiacus and Stephanopyxis.* Selvaraj *et al.* (2003) recorded *Thalassionema, Coscinodiscus, Pleurosigma, Skeletonema and Thalassiosira* as the most dominant. He also noted that the dinoflagellate *C.furca* and *P.depressum* were present most of the year.

The present study also made similar observations. In Vizhinjam bay the dominant diatoms were *T.favus, R.alata, B.moblinensis, B. sinensis, C.curvisietus, B. malleus,* *T.nitzchioides* and the dinoflagelalte *C.furca, Dinophysis* and *Peridinium*. In the sea region except *R. alata, B.sinensis, B.malleus, T.nitzschioides* and *C. furca* all other species were recorded as the dominant species. In addition, the diatom *C. lorenzianus* was also recorded as the dominant form. At Chombala *T.nitzshioides, B.sinensis, B.mobiliensis, T.subtils, D.sol. Coscinodiscus, A.japonica, T.frauenfeldii, F.ocenica, N.sigma, T.favus and the dinoflagellate C.furca* and *P.micans* were dominant with *Noctiluca, Gymnodinium* and *C.marina* dominating in certain months. On comparison it was found that the diatom *C.curvisietus* and the dinoflagelalte *Dinophysis* more unique to Vizhinjam and *Gymnodinium* and *C.marina* to Chombala. Except this, the community structure was similar, with diatoms dominating at both the stations.

The species evenness and diversity values were low during bloom events. During bloom events the species diversity is usually very low as the community is dominated by one or a few species. Devassy and Bhattathiri (1974) who studied the phytoplankton ecology of Cochin backwaters noted the lowest diversity of 0.64 during a bloom of *N.sigma*. It reached a maximum of 4.50 with values exceeding 4 throughout the monsoon. Tiwari and Nair (1998) noted that diversity varied between 0.29 to 3.61 with the lowest during the bloom of *Skeletonema.* The pre-monsoon months recorded comparatively higher diversity with intermittent increase in diversity in some other months. The highest diversity was recorded in July 03 at Chombala. The lowest diversity recorded was during the bloom of *C.marina* in September. At Vizhinjam the lowest diversity and evenness values were observed in May and October 2002 due to a bloom of *C.curvisetus* and in August 2002 due to *Fragilaria oceanica* In October 2002 even though *C.curvisetus* was present in increased concentration plankton diversity was also comparatively higher indicating that the conditions in October were suitable for the existence of many species.

CHAPTER II

2. BLOOM DYNAMICS OF PHYTOPLANKTON ALONG THE KERALA COAST

2.1. INTRODUCTION

Planktonic blooms in the marine system can be broadly classified into two types, 'spring blooms' and 'red tides'. Seasonal blooms occur annually, mainly as a result of changes in temperature and nutrient availability whereas red tides are localized outbreaks and occur due to a variety of reasons which are characteristic of each species and locality (Richardson, 1997). According to Cushing (1959), spring and autumn blooms which are typical of temperate waters and are mainly diatom events, occur during the period when there is a break in temperature stratification and the waters are well mixed, allowing phytoplankton, nutrient and light simultaneously to be in the surface waters prior to the development of grazing populations. The marine environment provides many different niches for phytoplankton species. The species residing within each niche has specific combination of requirements to the external environment. The degree to which the ecophysiological requirements of the species are matched by the physical and chemical habitats determine the blooming of these species. Studies on bloom dynamics will thus help in developing predictive models and for putting forth management measures at the earliest.

Several researchers have focused their attention on bloom dynamics, through which they have tried to identify the major reasons for the selection of these harmful species, in preference to the normal flora of the region and their sudden proliferation. Paerl (1988) has reviewed the major reasons for the occurrence of nuisance blooms in coastal, estuarine and inland waters. It is generally held that HAB outbreaks often follow a period of intense rainfall and runoff which increases water mass stratification, possibly enclosing a patch of chemically modified surface layer of water favourable for phytoplankton growth (Smayda, 1995). According to Paerl (1988), in stratified waters, motility allows a red tide organism to orient itself near the surface during the photosynthetically active day light hours while having the option of seeking deeper nutrient rich waters during potentially photoinhibitory mid day or night time hours. This favours their bloom over the less motile phytoplankton taxa which coexist during the initiation of bloom. Ryther (1955), Eppley and Harrison (1975) and Hartwell (1975) have studied the roles that vertical and horizontal water column stability play in the build up and persistence of bloom population. Initiation of *Pseudonitzschia* sp bloom in Penncove Washington has been linked strongly to stratification by Trainer *et al.* (1998).

Physical factors such as wind driven currents, tides, upwelling and downwelling, convergence and divergence and related frontal boundaries have also been indicated as initiation factors for red tide formation (Carreto *et al.,* 1986; Franks and Anderson, 1997; Tester and Steidinger, 1997). Bloom of the chrysophyte *Aureococcus anaphagefferens* has been associated with high salinities following anomalous winter and spring drought periods characterised by rainfall levels below the average of previous four decades (Cosper *et al*., 1987). A study on the development of a bloom of *Gonyalux polyedra* in Katsela bay, Adriatic sea by Marasovic *et al.* (1991) links the increased phytoplankton density to lowered salinities and higher temperatures. Bloom of *Aureococcus anaphagefferens* has been linked to a combination of physicochemical and hydrographic parameters in a study conducted by Bricelj and Lonsdale (1997). Relationship between *Noctiluca* swarming and hydrological features of the western coast of Brittany was studied by Le Levre *et al.* (1990).

Bloom of a species is further supported by large scale meteorological changes, anomalous weather events like *El Nino*, upwelling of nutrient rich bottom waters, heavy precipitation and runoff, eutrophication and biological factors like species competition and differential grazing (Maclean, 1987; Van Dolah, 2000; Yin 2003). Meteorological factors like wind speed and direction, rainfall have been reported to be important in the initiation of the bloom. In addition to increasing water mass stratification, rainwater brings in a fresh input of nutrients, which favours bloom formation. A massive bloom of the dinoflagellate *Karenia digitata* has been linked to distinct weather patterns, hydrographic and chemical factors by Yang and Hodgkiss (2004).

Nutrient enrichment in coastal waters is generally regarded as one of the major reason for the increased occurrence of algal blooms, especially red tides. There has been an increased input of nitrogen and phosphorous to the coastal waters mainly as a result of anthropogenic activities resulting in the transformation of previously pristine or oligotrophic coastal waters to eutrophic conditions. This has been accompanied by a corresponding increase in the appearance and persistence of algal blooms. Eutrophication from anthropogenic inputs has been linked to the increased recurrence of blooms in Tolo harbour, Hong Kong (Lam and Ho, 1989) and in Seto inland sea (Kotani *et al.*, 2001). With governmental regulations against anthropogenic inputs, the red tide occurrences were brought down in both the areas clearly supporting the relation between eutrophication and HAB occurrence. Paerl (1988) in his review has concluded that favourable physical conditions must act synergistically with nutrient enrichment to yield maximum biomass. The relationship between high phosphate loading and reduced salinity leading to the development of diatom and blue green algal bloom in Peel-Harvey estuarine system has been studied by Lukatlelich and Mc Comb (1986). Increased ground water and atmospheric deposition of nitrogen to coastal waters derived mainly from urban, industrial and agricultural sources has been linked to expansion of HAB's by Paerl (1997). Altered ratios of major nutrients has been found to be more significant than the total concentration of nutrients in the increased recurrence of HAB's because it results in selective stimulation HAB species over the others (Smayda, 1990). Radach *et al.* (1990) has studied the change in phytoplankton composition over a 23 year period at Helgoland, Germany and has linked the change from a diatom dominated to a dinoflagellate dominated community with general nutrient enrichment and altered nutrient ratios of the region. Selection of harmful species as a result of altered nutrient ratios has also been suggested by Anderson (1995) and Richardson (1997). Hodgkiss and Ho (1997) who reviewed the studies on bloom dynamics done in Tolo harbour, Japan and North European coastal waters supports this theory.

Along the Indian coast, occurrence of algal blooms are more prevalent along the west than on the east coast. Algal blooms particularly HAB occurrences along the Indian coast has been reviewed by Karunasagar and Karunasagar (1990). Diatoms have been observed to bloom regularly along the Indian coast during June to October. Bloom of the diatoms has been reported by Nair and Subarahamnayan (1955); Ramamirtham and Jayaraman (1963); Ramamuthy *et al.* (1972); Devassy (1974) and by Devassy and Bhattathiri (1974). Phytoplankton blooms which occurred along the Indian coast during the period from 1982 to 1987 has been documented by Mathew *et al.* (1988).

Of the harmful algae, the species most often reported from our waters is the dinoflagellate *Noctiluca* species. Uhling and Sahling (1990) Huang and Qi (1997), Jocelyn (2000), and Umani (2004) have all studied the population dynamics of *Noctiluca scintillans* in detail. *Noctiluca* blooms has been reported and studied in the coastal waters along south west coast of India by Bhimachar and George (1950); Prasad and Jayaraman (1954); Subramanyan (1959a); Venugopal *et al.* (1979); Devassy and Nair (1987); Mathew *et al.*, (1988); Katty *et al.* (1988); Nayak *et al.*, (2000) and by Eashwar *et al.* (2001). Along the east coast, *Noctiuca* blooms along with associated mortality has been reported as early as 1935 by Aiyar (1936) along the Madras coast. It was reported by Sasikumar *et al.* (1989) in Kalpakkam waters along the Tamilnadu coast, with associated fish mortality. Bloom of other dinoflagellates, *Gonyaulax polygramma* was recorded along southwest coast by Prakash and Sharma (1964) and along the coastal waters off Cochin by Gopinathan and Pillai (1976). Dinoflagellate bloom events of *Gymnodinium mikimotoi* and associated benthic fish mortality was reported by Karunasagar and Karunasagar (1992). *Gymnodinium mikimotoi* blooms associated with large scale mortality in fish (Karunasagar and Karunasagar, 1993) and shrimp farms at Kundapur, southwest coast of India (Karunasagar *et al.*, 1993) has also been reported.

The filamentous blue green alga *Trichodesmium erythraeum* is the most common red tide organism in the tropical seas and occurs as a regular feature from February to April in Arabian Sea. Bloom of *Trichodesmium* has been reported off the Mangalore coast by Prabhu *et al.* (1965), around Minicoy island by Naghabhushanam (1967), by Qasim (1970) in Laccadive sea, along the Goa by Ramamurthy *et al.* (1972) and Devassy *et al.* (1978). More recently, investigations by Sreekumaran *et al.* (1992) has shown that the algae regularly blooms in the Arabian sea during the pre-monsoon season every year. No mortality of marine organisms has been reported in the above bloom events but recently Naqvi *et al.* (1998) has reported fish mortality associated with the bloom of *Trichodesmium* off Cochin.

Another harmful algae which regularly blooms along the Calicut coast of Kerala is the marine rapidophyte *Chattonella marina*. Even though blooms and associated mortalities due to a phytoflagellate off the Calicut coast was reported as early as 1917 by Hornell and by Jacob and Menon (1948), it was identified as *Hornellia marina* by Subramanyan in 1954. Its nomenclature has been now changed to *Chattonella marina* (Hara et Chihara 1982). Imai and Itoh, (1986, 1987) have studied the annual life cycle and population dynamics of the species in the Seto inland sea, Japan. Mortality in fishes exposed to blooms of *Chattonella marina* has been studied by Matsusato and Kobayashi, 1974; Ishimatsu *et al.*, 1990; Doi *et al.*, 1981; Endo *et al.*, 1992; Toyoshima *et al.*, 1985 and Tiffany, 2001. Recently neurotoxins have been isolated from these organisms (Onoue and Nozawa, 1989). *Chattonella spp* though reported as the major killer of fishes in aquaculture farms of Japan has not caused any severe problems along our coast, except for the small scale regional fish kills during the time of bloom

In all these studies, the major physicochemical and biological parameters at the time of the bloom are monitored and presented. The concentration of major nutrients was monitored and related to a bloom of *Fragilaria oceanica* by Devassy (1974). Physical and chemical parameters during a *Trichodesmium* bloom was studied by Qasim (1970) and Devassy *et al.* (1978). Reasons for the red tide along the south Kerala coast was studied by Venugopal *et al.* (1979). Bacteriological and physicochemical factors associated with *Noctiluca milaris* bloom along Mangalore, southwest coast of India was done by Nayak *et al.* (2000). The present chapter describes the dynamics of algal blooms which occurred along the Kerala coast during the study period. The harmful algal species recorded at the study sites and their period of occurrence is also presented.

2.2. MATERIALS AND METHODS

2.2.1. BLOOM SAMPLING

Phytoplankton samples were collected at monthly intervals from Vizhinjam and Chombala. Along with this, intensive sampling was done at locations where a visible appearance of the bloom was reported. Samples for the analysis of major physicochemical and biological parameters were collected in both the instances and estimated according to the methodology described in Chapter I.

A particular phytoplankton was considered to be in bloom condition when its cell densities increased at least ten times of the normal. Also, increased densities of phytoplankton need not always result in visible colouration. A toxic species can cause a harmful response even if its densities are comparatively lower. Both these factors were considered in identifying the bloom at these stations.

2.2.2. TOXIN ANALYSIS

The water, bivalve and fish samples from the areas of study were analysed at CIFT (Central Institute of Fisheries Technology) by mouse bioassay for the presence of PSP/DSP toxin. The results of this analysis are presented in Appendix. I.

2.3. RESULTS

Analysis of phytoplankton samples collected during the 24-month study period revealed the presence of harmful bloom forming species at all the three stations. An account of these is presented first. Following this, the nontoxic and toxic blooms which occurred during the study period and the environmental variations during their bloom period is described. The results of the targeted study done in September 2002, at three sites selected within the bloom area along the Calicut coast in North Kerala, when there was a heavy bloom of *Chattonella marina* and that at two sites at Narakkal in South Kerala during a harmful bloom of the same species is presented in detail. The negative impacts noticed during these harmful algal blooms along with the results of the toxin analysis of water and bivalve samples done at CIFT is also presented.

2.3.1. NORTH KERALA

CHOMBALA

2.3.1.1. RECORD OF TOXIC ALGAL SPECIES

Qualitative analysis is a prerequisite when preparing a database of the phytoplankton resource of the location. Recording the presence of a toxic algal species in the coastal waters is important even if it is a rare member of the phytoplankton community of the region, as there exists a possibility of sudden and spontaneous uncontrolled growth and multiplication of these species resulting in harmful blooms when the right conditions prevail. In addition to this, some dinoflagellate genera like *Dinophysis* have members which are toxic even at very low densities.

The qualitative and quantitative analysis of phytoplankton collected from Chombala revealed the presence of 10 phytoplankton species- *Noctiluca scintillans* (Macartney) Kofoid and Swezy 1921, *Gymnodinium mikimotoi* Miyake and Kominami ex Oda 1935, *Prorocentrum lima* (Ehrenberg) Dodge 1975, *Prorocentrum micans* Ehrenberg 1833, *Dinophysis caudata* Saville-Kent 1881, *Dinophysis acuminata* Claparede and Lachmann 1859, *Pseudo-nitzschia* sp H. Pergallo, *Pseudo-nitzschia pungens* (Grunow ex Cleve) Hasle, *Chattonella marina* (Subrahmanyan) Hara et Chihara 1982 *and Trichodesmium* spp with known records of toxicity. In Fig. 2.1, the months of occurrence of these harmful algae at Chombala is presented.

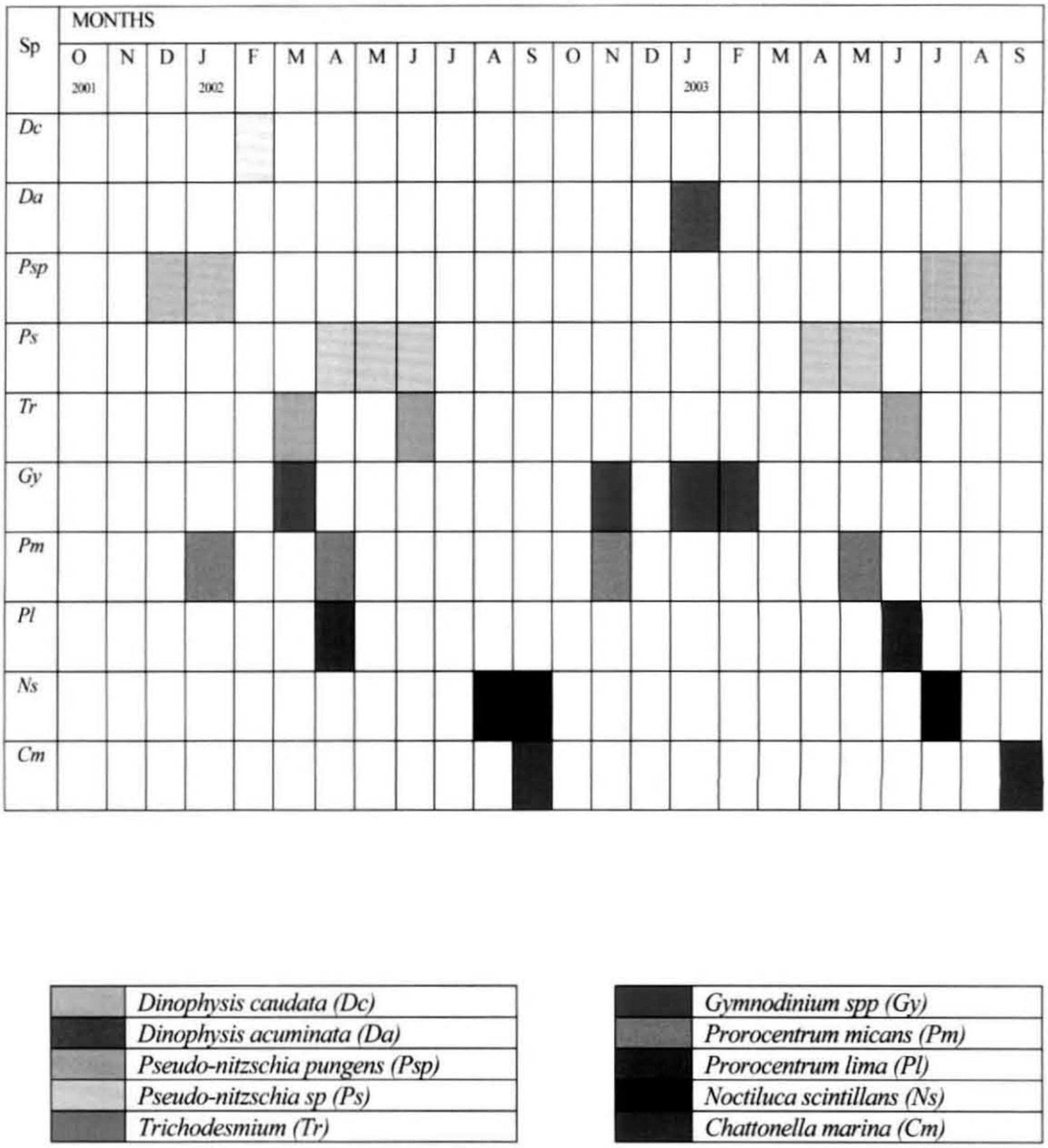
A. DINOFLAGELLATES

I. *Noctiluca scintillans* (Macartney) Kofoid and Swezy 1921
Classification and Cell structure

Division:	Pyrrophyta
Class:	Dinophyceae
Order:	Noctilucales
Family:	Noctilucaceae
Genus:	*Noctiluca*

Unarmored dinoflagellate, large (200 to >1 mm) subspherical inflated vegetative cell, with one flagellum and a striated tentacle. A ventral groove contains the flagellum, a tooth and a tentacle and is connected to a cystostome. The cytoplasm is vacuolated and can contain photosynthetic symbionts. Vegetative cell with eukaryotic nucleus. Gametes gymnodinioid; with dinokaryotic nucleus. Chloroplasts absent. The cells are colourless but may attain a green colour because of the presence of endosymbiotic flagellates. Phagotrophic (Pl. Ia).

Fig. 2.1. Representation of the months of occurrence of harmful algae at Chombala from October 2001 to September 2003.



Occurrence

Noctiluca scintillans was present in the months of August (3.7%) and September 2002 (0.05%) and in July 2003 (1.4%) at Chombala.

Toxin Chemistry and Toxicology

Noctiluca scintillans accumulates large amounts of ammonia in the vacuoles which maybe toxic to fish. It is found to feed heavily on fish eggs and zooplankton which leads to disruption in the food web.

II. *Gymnodinium mikimotoi* Miyake and Kominami ex Oda 1935

Classification and Cell structure

Division:	Pyrrophyta
Class:	Dinophyceae
Order:	Gymnodinales
Family:	Gymnodiniaceae
Genus:	*Gymnodinium*

Small broadly oval cell that is dorsoventrally compressed. Hypotheca exceeds epitheca, epitheca is broadly rounded and hypotheca is notched and slightly bilobed. Cingulum slightly premedian and displaced 2x cingular width. Apical groove-sulcus juncture characteristic. Sulcus slightly invades hypotheca, immediately to right is the proximal end of the apical groove which extends onto the dorsal epitheca and is straight. Ventral ridge inverted hook shape. Clustered pore field on left dorsal hypotheca. Chloroplasts present. Nucleus ellipsoidal and on left side near periphery (Pl. Ic).

Occurrence

Gymnodinium, a dinoflagellate genus with known toxicity shown by some of its members was present in the months of March and November 2002 and January (Pl. Id) and February 2003 at Chombala. The qualitative analysis of phytoplankton showed a very low percentage, 1.5% in March and 0.9% in November 2002 and relatively higher percentage of 17.9% and 45.5% in January and February 2003. In February 2003, the qualitative analysis showed the toxic species of the genera *Gymnodinium mikimotoi* to be the dominant species of the community.

Toxin Chemistry and Toxicology

G.mikimtoi produces both hemolytic and icthyotoxins and has caused damage in fish farms. Etiology poorly under stood and is thought to cause death due to the damage of epithelial surfaces of gills and digestive system.

III. *Prorocentrum* spp

Classification and Cell structure

Division:	Pyrrophyta
Class:	Dinophyceae
Order:	Prorocentrales
Family:	Prorocentraceae
Genus:	*Prorocentrum*

***i. Prorocentrum lima* (Ehrenberg) Dodge 1975**

Cells ovate, widest behind the middle in valve view, lenticulate to ellipsoidal in lateral view with a flattened central area. The anterior end of left and right valves is straight and triangularly concave respectively. Valve surface smooth, having trichocyst pores sparsely all over the surface except the central area. Length 30-40 µm, width 26-30 µm (Pl. Ie).

***ii. Prorocentrum micans* Ehrenberg 1833**

Medium sized, pyriform to heart shaped cell. Typically, in valve view, cell will have one convex side and one arched side. The convex arch profile is typically in the middle of the cell. In lateral view the cell is flattened. Valves with shallow depressions and post median radial pore fields as in some other *Prorocentrum* species (Pl. If).

Occurrence

Prorocentrum micans was present in the phytoplankton samples of the station in the months of January and November 2002 and May 2003 with a percentage of 2.5, 1.4 and 2.4 respectively. *Prorocentrum lima* formed a low percentage of 1.4 in April 2002 and 0.4% in June 2003 at the station.

Toxin Chemistry and Toxicology

P.lima produce several kinds of toxins such as okadaic acid and is sometimes called a ciguateric causing organism and as a DSP causing organism by others, but the implications in the food web is unclear. *Prorocentrum micans* is implicated in marine faunal kills but the causative mechanism is not yet clear.

IV. *Dinophysis* spp

Classification and Cell structure

Division:	Pyrrophyta
Class:	Dinophyceae
Order:	Dinophysiales
Family:	Dinophysiaceae
Genus:	*Dinophysis*

***i. Dinophysis caudata* Saville- Kent 1881**

Cells large, irregularly subovate with fairly distinctive long ventral projection. Ventral side of hypotheca undulate or straight. Dorsal side straight or slightly concave in the anterior half and straight or convex, running parallel with the ventral side in the posterior half. Anterior cingular list wide, supported by many posterior ribs, forming a wide and deep funnel like structure with very low epitheca on the bottom. Left sulcal list almost half of total length, supported by three ribs. Thecal plates thick areolated. Length 70-110 µm (Pl. Ig).

***ii. Dinophysis acuminata* Claparede et Lachmann 1819**

Cells oval or often elongated oval in lateral view. Dorsoventral depth longest near the middle, about half of the cell length. Epitheca low, flat or weakly convex, invisible in lateral view. Dorso-ventral depth of epitheca is ⅓ to ½ of hypotheca. Antapex is rounded and smooth or with two to four knob shaped small protuberances. Left sulcal list is rather narrow, often coarsely areolate, supported by three ribs, extending to ½ to ⅔ of cell length. Thecal plates thick areolated. Length 40-50 µm, dorso ventral depth 30-40µm (Pl. Ih).

Occurrence

Dinophysis acuminata was detected once in the study period in the month of January 2003 at a low percentage of 2.6 in the sample. *Dinophysis caudata* was also present once in the month of February 2002 at a low percentage of 1.85.

Toxin Chemistry and Toxicology

D.caudata is suspected to cause diarrhetic shellfish poisoning in human beings. Red tides associated with mass mortality in shell fish have also been reported. Blooms of *Dinophysis acuminata* are often associated with toxication of shellfish.

B. DIATOMS

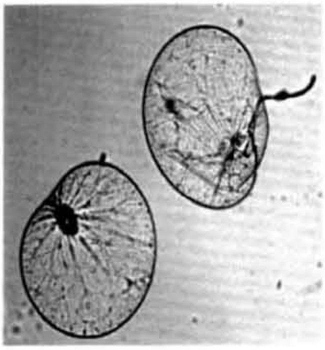
***Pseudo-nitzschia* spp H. Pergallo**
Classification and Cell structure

Division:	Chrysophyta
Class:	Bacillariophyceae
Order:	Bacillariales
Suborder:	Bacillariineae
Family:	Bacillariaceae
Genus:	*Pseudo-nitzschia*

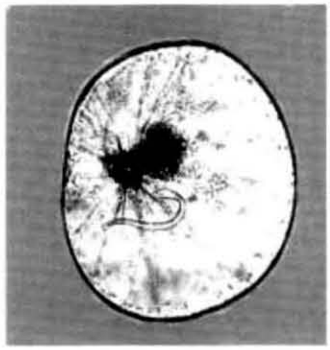
Generic characters

Cells of *Pseudo-nitzschia* can be easily distinguished from that of *Nitzschia* spp by the stepped chains formed by overlap of valve ends. Cells strongly elongate, rectangular or longer overlap of valve ends. Chains motile. Raphe strongly eccentric. Raphe not raised above the general level of the valve. Valve face interstriae often more than one to each fibula. Central larger interspace in most species. Valve face slightly curved or flattened, not undulated.

PLATE I



a.



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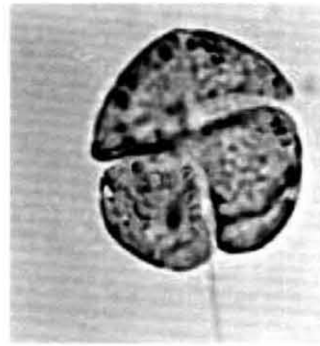
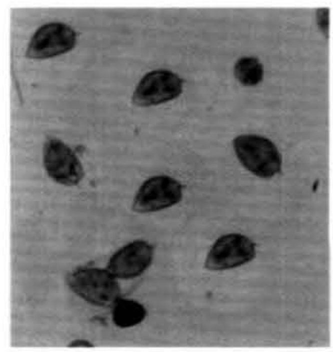


c.

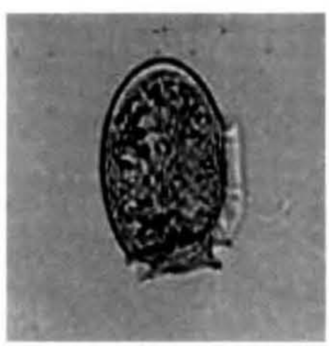
d.

e

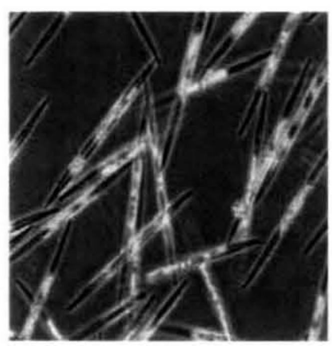


f.

g



h



i

a *N. scintillans*- Chombala	(x 10x)	f. *Prorocentrum micans*	(x100x)
b. *N. scintillans*- Vizhinjam	(x10x)	g. *Dinophysis caudata*	(x 40 x)
c. *Gymnodinium mikimotoi*	(x 100x)	h. *Dinophysis acuminata*	(x 40 x)
d. *Gymnodinium* sp	(x100x)	i. *Pseudo- nitzschia pungens*	(x 40 x)
e. *Prorocentrum lima*	(x100x)		

Valves narrowly lanceolate to fusiform and linear with round or pointed ends. Transapical axis heteropolar in some species. Striae structure usually too delicate to resolve with LM. Chloroplasts two plates, lying along the girdle one on either side of the median transapical plane. Resting spores unknown. Species of this genus are morphologically very similar making its identification upto species level very difficult.

i. Pseudo-nitzschia pungens **(Grunow ex Cleve) Hasle**

Girdle view: Fusiform, pervalvar axis upto 8µm. Fibulae and/ or ends of interstriae distinct. Overlap of cells in chains considerable, close to one-third or more of cell length.

Valve view: Larger specimens linear with distinctly pointed ends and smaller specimens more fusiform. Strongly silicified. Interstriae visible in water mounts. Fibulae distinct on cleaned valves on permanent mounts, striae biseriate, the two rows of poroids discernible with LM under optical conditions (Pl. Ii).

Occurrence

Pseudo-nitzschia spp, a pennate genera with amnesic shellfish poisoning shown by many of its members showed a constant presence in the phytoplankton sample in the warmer months of the year (Pl. IIa). Its presence was noted in the months of April (4%), May (0.4%) and June 2002 (0.6%). In the second year its presence in the community was much more prominent with 22% in April 2003 and 16.3% in May 2003. *Pseudo-nitzschia pungens* proved to produce amnesic shellfish poisoning was present in January 2002 (2.5%) and in July 2003 (1.4%). It exhibited a dominant presence in December 2001(24%) and in August 2003 (23.3%).

Toxin Chemistry and Toxicology

Amnesic shellfish poisoning or Domoic acid poisoning has been proved to be caused by members of the genera *Pseudo-nitzschia* spp. Domoic acid binds to the Kainate type of glutamate receptors and in presence of endogenous glutamate causes massive depolarisation of the neurons with a subsequent increase in cellular Ca^{2+} leading to neuronal swelling and death.

D. RAPIDOPHYTES

I. Chattonella marina **(Subrahmanyan) Hara et Chihara 1982**

Classification and Cell structure

Division:	Rapidophyta
Class:	Rapidophyceae
Order:	Chattonales
Family:	Chattonaceae
Genus:	*Chattonella*

Cell 30-70µm long and 20-30µm wide, asymmetrical in lateral view, slightly flattened, oblong to obovoid in shape with a posterior tail. The two subequal flagella are approximately equal to the length of the cell and emerge from the bottom of an anterior depression in the cell. Chloroplasts many green to yellowish brown, ellipsoid chloroplasts are arranged radially. Naked pyrenoid located on the inner pole of the chloroplast. Tear shaped nucleus, situated in the center of the cell. Contractile vacuoles, eyespots and mucocysts absent (Pl. IIb). Asexual reproduction by binary fission. Diplontic life cycle, with cyst formation after meiosis in vegetative cells. The hemispherical cysts are with a simple pore on the top and a circular wing on the bottom edge.

Occurrence

Chattonella marina formed regular and harmful blooms at the station in the post-monsoon season. It entirely dominated the phytoplankton flora with 84% of the community being dominated by this species in September 2002 and with 91.5% in September 2003.

Toxin Chemistry and Toxicology

The species has been reported to cause ichthyotoxicity worldwide. The species produces poorly characterized neurotoxic and haemoagglutinating compounds as well as superoxide and hydroxyl radicals that cause oedema formation in gill lamellae resulting in suffocation and death.

D. CYANOPHYTA

***I. Trichodesmium* spp**

Classification and Cell structure

Phylum:	Cyanophyta
Class:	Cyanophyceae
Order:	Nostocales
Family:	Oscillatoriaceae

Colonies of *Trichodesmium* consist of many trichomes bundled together parallel or twisted in a rope like fashion. Colonies are usually buoyant and are about 1x 3mm in size. They usually appear golden brown in colour, but can vary from gray and brown to red. Cell diameter ranges from 7 to 16 µm, and cells are usually as long as they are wide or can be upto twice as long as they are wide (Pl. IIc).

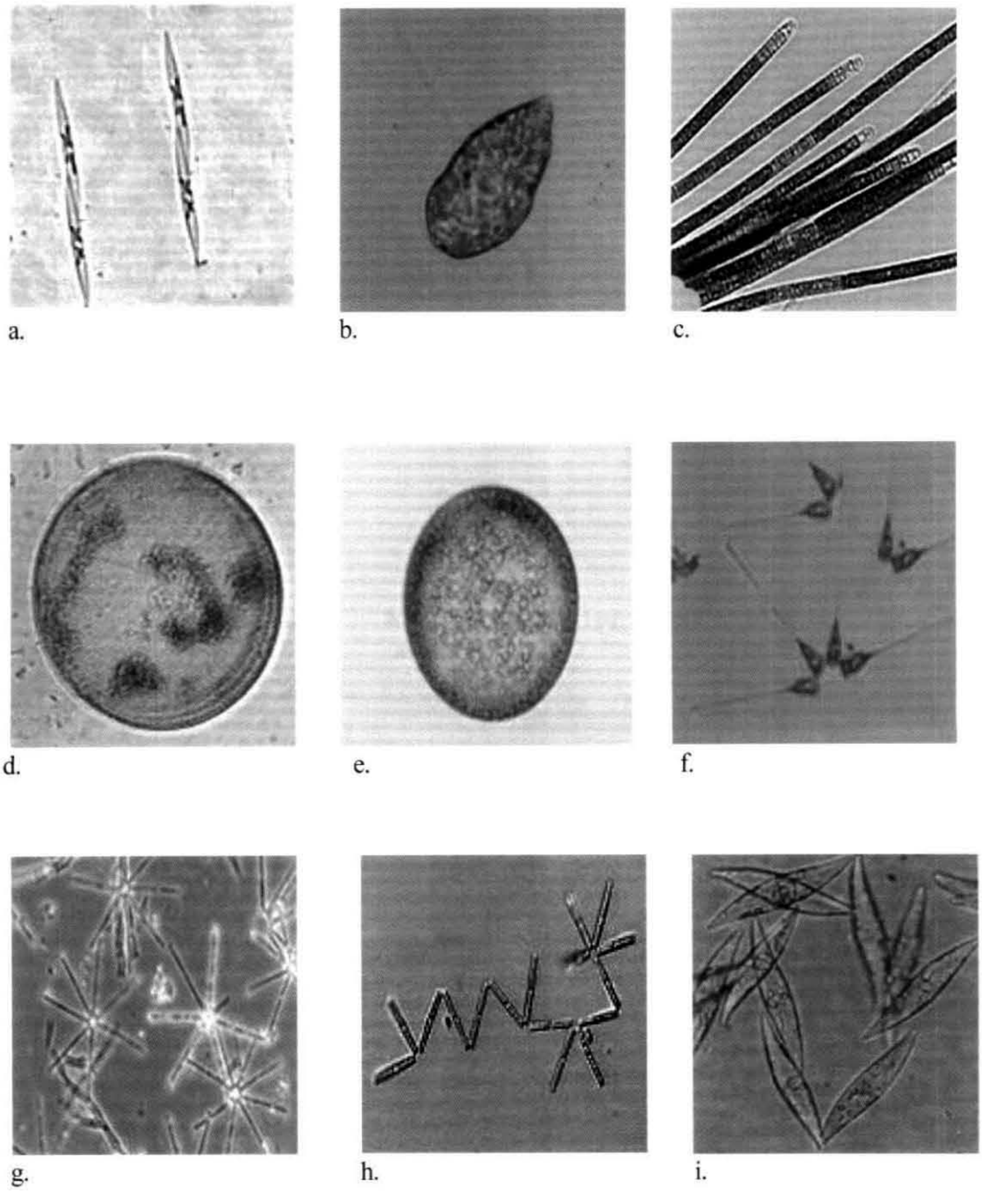
Occurrence

Trichodesmium spp was present in March (5%) and June 2002 (0.3%) and in June 2003 (2.2 %).

Toxin Chemistry and Toxicology

T.thiebautii has recently been identified to possess a neurotoxin which is similar in action to anatoxin-a. This planktonic tropical species has been shown to be toxic to some, but not all marine invertebrates which graze upon it. Further more, there are incidences of reports of breathing difficulties from people who have been near the vicinity of red tide blooms of *Trichodesmium*. Other species may also be toxic. Fishes have been found to avoid the bloom areas.

PLATE II



a. Pseudo-nitzschia sp (x 40 x)
b. Chattonella marina (x 10 x)
c. Trichodesmium sp (x 10 x)
d. Coscinodiscus asteromphalus (x 10 x)
e. Coscinodiscus janischii (x 10x)
f. Asterionella japonica (x 100 x)
g. Thalassiothris frauenfeldii (x 100 x)
h. Thalassionema nitzschioides (x 100x)
i. Pleurosigma normanii (x 100x)

2.3.1.2. NON TOXIC BLOOMS

The nontoxic blooms at Chombala were mainly diatom blooms. The diatoms were found to increase in density and diversity between the late pre-monsoon months and early monsoon months at Chombala. There was however no visible coloration at the sampling site during any of these diatom bloom events.

I. *Coscinodiscus* Blooms

During the study period, five blooms of *Coscinodiscus* spp were observed along the Kerala coast. *Coscinodiscus asteromphalus* and *C. janischii* bloomed only at Calicut and *C. sublineatus* at Vizhinjam sea and bay. The details regarding the bloom is given below and summarised in Table. 2.1.

Phytoplankton characteristics

In May 2002, the centric diatom *Coscinodiscus asteromphalus* (Pl. IId) was present at a high density of 53,000 cells l^{-1}. The other major phytoplankton present were *Pleurosigma elongatum* at a density of 5000 cells l^{-1} and *Biddulphia mobiliensis* at a density of 2000 cells l^{-1}. Qualitative analysis showed that 65% of the community was constituted by *Coscinodiscus*. Lower diversity (1.375) and evenness value (0.452) were also recorded. The gross and net productivity during the bloom period was 1.28 and 0.85 gC/m^3/day. The pigment concentrations were slightly higher than during the pre-bloom period with values of 5.23, 1.41, 1.78 and 0.171 mg m^{-3} for Chlorophyll *a, b, c* and carotenoids respectively. In August 2002 there was again a bloom of *C.asteromphalus* in the coastal waters of Chombala at a density of 4,10,000 cells l^{-1}. *Nitzschia sigma* at a density of 12,000 cells l^{-1} was the co-occurring dominant diatom. The GP and NP were high with estimated values of 4.83 and 2.91 gC/m^3/day at the site. Chl *a, c* and carotenoid values were very high with values of 148.23, 20.15 and 1.854 mg m^{-3} while Chl *b* was absent.

In July 2002 *Coscinodiscus janischi* (Pl. IIe) was present at a density of 35,000 cells l^{-1} and *Thalassiosira subtilis* at a density of 32,000 cells l^{-1}. The diversity and evenness values were high, 1.998 and 0.804 respectively. GP and NP were higher with values of 2.44 and 0.82 gc/m^3/day, Chl *a* and *b* were 29.72 and 2.06 mg m^{-3} respectively.

Environmental variations

There was a decrease in AT and SST from 32 and 34° C in April to 34 and 31° C in May. A similar decrease in temperatures from 29° C in July to 27° C in August was also noted in the next bloom event of the same species and when the cell densities were also the highest. Salinity decreased from 33 to 32 ppt in both the instances. The dissolved oxygen content was lower with a value of 3.70 mg l^{-1} in May whereas during the second instance a higher value of 4.83 mg l^{-1} was obtained. The TSS content of the water was higher during both the bloom periods with a value of 48.5 mg l^{-1} in May and 50.2 mg l^{-1} in August 2002. Of the nutrients, depletion in the concentration of ammonia, nitrate and nitrite was noted in the first bloom in May. Ammonia decreased from a concentration of 22.62 in April to 12.62 µmol l^{-1} in May and nitrate from 0.58 to 0.1µmol l^{-1} whereas nitrite showed complete depletion. The concentration of phosphate was however higher during the bloom period with a value of 0.48 which was slightly higher than 0.21µmol l^{-1} the previous month. The bloom in August also showed a depletion of ammonia from a value of 0.64 in July to 0.34 µmol l^{-1} in August where as phosphate, nitrate and nitrite were present at concentrations higher than the previous months with values of 2.99, 3.50 and 0.21 µmol l^{-1} respectively .

The bloom of *C.janischii* in July 2002 also followed a lowering of AT and SST from 31 to 29° C whereas there was an increase in salinity from 32 in June to 33 ppt in July. TSS was high with a value of 27 mg l^{-1} similar to that of the earlier blooms of *Coscinosdiscus* spp. Ammonia, which was completely depleted in the preceding month, increased to 0.64 µmol l^{-1} in July. Phosphate, nitrate and nitrite concentration were also higher than in July with values of 1.69, 3.5 and 0.20 µmol l^{-1} respectively.

II. *Asterionella japonica* Cleve

Phytoplankton characteristics

In June 2002, the pennate diatom *Asterionella japonica* (Pl. IIf) reached high densities of 3.2×10^5 cells l^{-1} at the station. *B.mobiliensis* a centric diatom with a density of 85,000 cells l^{-1} was the second dominant member. Qualitative analysis showed that *A.japonica* constituted 60% and *B.mobiliensis* 21% of the phytoplankton community. The diversity (1.419) and evenness values (0.474) were also low. GP and NP of 1.221 and 0.407 gC/m^3/day and Chl *a, b, c* and carotenoid value of 21.12, 0, 4.3 and 0.881 mg m^{-3} was obtained.

Environmental variations

The bloom of *A. japonica* followed a lowering of AT from 31 to 30 °C and SST from 31 to 29°C. Salinity was 32 ppt. Dissolved oxygen was higher with a value of 4.61 mg l^{-1}. The TSS was low when compared to the *Coscinodiscus* bloom periods but was higher than other months with a value of 12.9 mg l^{-1}. Ammonia showed a complete depletion from 12.62 µmol l^{-1} in May and phosphate from a value of 0.48 to 0.15 µmol l^{-1}. Nitrate and nitrite showed a very slight increase from 0.10 and 0 to 0.35 and 0.01µmol l^{-1}.

Table. 2.1. Environmental parameters, cell density and diversity indices during the bloom of the diatom *Coscinodiscus* spp at Chombala and at Vizhinjam

	CHOMBALA			**VIZHINJAM BAY**	**VIZHINJAM SEA**
Phytoplankton species	*C. asteromphalus*	*C. janischii*	*C. asteromphalus*	*C. sublineatus*	*C. sublineatus*
Period of occurrence	May 2002	July 2002	August 2002	September 2002	September 2002
Cell density (cells l^{-1})	53,000	35,000	4,10,000	128500	82850
At.T (^{o}C)	31	29	27	27.0	27.00
SST (^{o}C)	31	29	27	28.0	27.00
Salinity (ppt)	32	33	32	31.0	33.0
pH	7.94	7.97	8.06	8.18	8.22
Dissolved oxygen (mg l^{-1})	3.7	4.89	4.83	3.26	3.68
Total suspended solids (mg l^{-1})	48.5	27	50.2	14.20	10.40
Biochemical oxygen demand (mg l^{-1})	2.7	1.5	2.7	2.50	1.80
Ammonia (µmol l^{-1})	12.62	0.64	0.34	1.96	1.63
Nitrate (µmol l^{-1})	0.1	3.5	3.5	0.65	0.01
Nitrite (µmol l^{-1})	0	0.2	0.21	0.88	1.04
Dissolved inorganic nitrogen (DIN) (µmol l^{-1})	12.72	4.34	4.05	3.49	2.68
Phosphate (µmol l^{-1}) (DIP)	0.48	1.69	2.99	0.34	0.66
N:P	26.7	2.58	1.35	10.27	4.07
Rainfall (cm)	450	344	418	20	20
Species numbers	21	12	17	14	14
Margalef's Species richness	4.345	2.4	3.475	2.823	2.823
Pileou's evenness	0.452	0.804	0.679	0.620	0.5618
Shannon- Wiener	1.375	1.998	1.923	1.637	1.4827

III. *Thalassiothrix frauenfeldii* Grunow

In the second year diatom blooms were recorded in the months of March, April and May 2003.

Phytoplankton characteristics

In March *Thalassiothrix frauenfeldii* (Pl.IIg) was present at a density of 88,500 cells l^{-1} and *Melosira sulcata* at a density of 42,225 cells l^{-1}. A diversity of 1.67 and evenness value of 0.931 was obtained. GP and NP values of 1.278 and 1.460 gc/m^3/day were obtained in March, while Chl *a, b* and *c* values of 14.76, 0.45 and 3.130 mg m^{-3} were obtained.

Environmental variations

The bloom followed the lowering of AT and SST from 28 and 29 to 27°C. Salinity was slightly higher than that recorded during the earlier blooms with a value of 34 ppt. Dissolved oxygen lowered from 4.55 to 4.36 mg l^{-1} and TSS increased slightly from 2.5 to 4.1 mg l^{-1}. Ammonia showed a complete depletion from 3.16 μmol l^{-1} in February to 0 in March. Nitrate also showed a similar depletion from 1.34 μmol l^{-1} in January to 0 in February and March and nitrite from 0.34 to 0.08 μmol l^{-1}. Phosphate was however higher during the bloom month with value of 1.91μmol l^{-1} during the bloom which was higher than 1.25 μmol l^{-1} in February.

IV. Thalassionema nitzschioides Grunow

Phytoplankton characteristics

The bloom in March was succeeded by a member of the same family as that of *Thalassiothrix, Thalassionema nitzschioides* (Pl.IIh) which was present at a density of 3,75,600 cells l^{-1}. Diversity and evenness recorded values of 2.094 and 0.843 in this month. GP and NP values of 1.04 and 1.454 gC/m^3/day and Chl *a, b* and *c* values of 6.11, 0.480 and 1.16 mg/m^3 were obtained.

Environmental variations

Both the AT and SST increased from 27 to 32 and 30° C. Salinity was the same of 34 ppt. Dissolved oxygen was very high with a value of 7.07 mg l^{-1}. TSS increased from 4.1 to 16 mg l^{-1}. BOD values were higher with a value of 9.6 mg l^{-1}. The concentration of all the nutrients were low. Ammonia was absent while phosphate, nitrate and nitrite values were low of 0.82, 0.04 and 0.01μmol l^{-1} respectively.

IV. *Pleurosigma normanii* Ralfs

Phytoplankton characteristics

In May, the diatom *Pleurosigma normanii* (Pl. IIi) was present at a very high density of 26,40,000 cells l^{-1} and an unidentified blue green algae at a density of 1,29,800 cells l^{-1}. The harmful algae *Gymnodinium* sp was also present at a density of 3850 cells l^{-1}. High diversity of 2.566 and evenness of 0.818 was recorded in these months which indicated that the blooms were not monospecific. GP and NP pf 2.05 and 1.211 gC/m^3/day and Chl *a, b* and *c* values of 18.1,1.41 and 3.63 mg/m^3 were obtained.

Environmental variations

The atmospheric temperature and salinity were the highest, 33°C and 36 ppt during the bloom of *P.normanii.* Dissolved oxygen lowered from 7.07 to 5.37 mg l^{-1}. TSS was higher with a value of 29.5 mg l^{-1}. BOD was lower than in April with value of 3.3 mg l^{-1}. Ammonia was nil whereas phosphate, nitrate and nitrite values increased from low values to 1.2, 0.2 and 0.2 in May. A comparison of the major physicochemical parameters during the bloom of pennate diatoms is given in Table. 2.2.

2.3.1.3. HARMFUL BLOOMS

I. *Chattonella marina* –September 2002

Chattonella marina, a golden brown rapidophyte which has been implicated in many harmful events world wide, has been observed to bloom regularly along the Calicut coast, in the transition period between southwest and northeast monsoon season. During the study period, the bloom of the species was observed in September in both the years. A widespread and high density bloom of *Chattonella marina* occurred in the first week of September 2002 along the Calicut coast. The bloom showed a discontinuous distribution and extended over a distance of about 50 kilometers along the coast, from Konadu near Calicut to Mahe near Thalassery. The region of occurrence of the bloom along with sampling sites is given in Pl. IIIa. The muddy green coloured bloom (Pl. IIIb) was very noticeable at Kappad, where it extended from the shoreline to about a distance of about 3 kilometers towards the sea. It was visible as streaks and patches in other areas. At Kappad and Konadu, sampling was done on 1^{st}, 8^{th} and 22^{nd} day starting with the visible occurrence of the bloom. Bloom of the species which was confined to Konadu- Kappad region in the first week, soon spread to neighbouring Chombala and Mahe by the end of the following week. To cover this region, Chombala was included in the last two samplings.

Phytoplankton characteristics

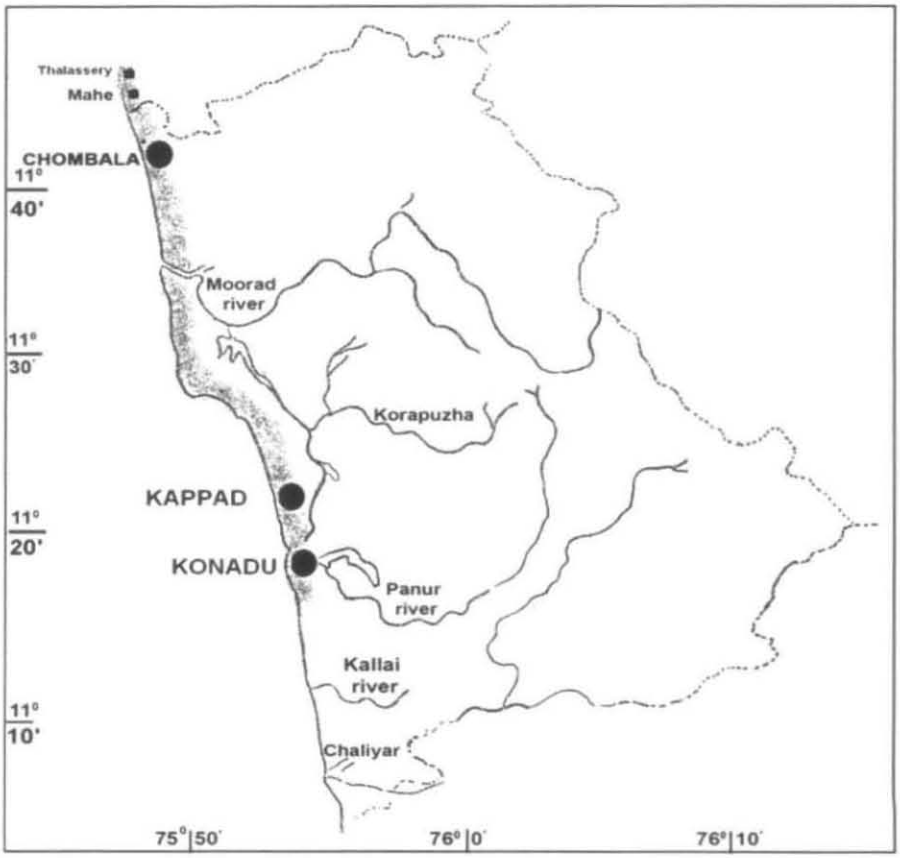
Kappad

Analysis of phytoplankton showed a very high density of *C. marina,* $28x10^7$ cells l^{-1} at Kappad on the first day. Other phytoplankton were few, but were present in high densities and

Table. 2.2. Environmental parameters, cell density and diversity indices during the bloom of pennate diatoms at Chombala and Vizhinjam

CHOMBALA					**VIZHINJAM BAY**	**VIZHINJAM SEA**
Phytoplankton species	*A japonica*	*T frauenfeldii*	*T nitzschioides*	*P normanii*	*F oceanica*	*F oceanica*
Period of occurrence	June 2002	March 2003	April 2003	May 2003	August 2002	August 2002
Cell density (cells l^{-1})	320000	88500	375600	2640000	498000	460000
At.T (^{o}C)	30	27	32	33	29.0	29.00
SST (^{o}C)	29	27	30	30	29.0	27.00
Salinity (ppt)	32	34	34	36	32.0	33.0
pH	7.81	8.09	8.2	8.14	7.86	7.90
Dissolved oxygen (mg l^{-1})	4.61	4.36	7.07	5.37	4.85	4.20
Total suspended solids (mg l^{-1})	12.9	4.1	16	29.5	4.57	2.50
Biochemical oxygen demand (mg l^{-1})	1.6	1.1	4.3	1.5	0.50	0.50
Ammonia (µmol l^{-1})	0	0	0	0	12.40	5.11
Nitrate (µmol l^{-1})	0.35	0	0.04	0.2	2.84	2.84
Nitrite (µmol l^{-1})	0.01	0.08	0.01	0.2	3.82	2.21
Dissolved inorganic nitrogen (DIN) (µmol l^{-1})	0.36	0.08	0.05	0.4	19.06	10.16
Phosphate (µmol l^{-1})	0.15	1.91	0.82	1.2	2.50	2.50
N:P	2.46	0.04	0.06	0.33	7.62	4.06
Rainfall (cm)	667	2	199	90	108	108
Species numbers	20	9	6	12	14	17
Margalef's Species richness	4.13	1.09	2.39	4.78	2.825	3.478
Pileou's evenness	0.474	0.931	0.843	0.816	0.476	0.340
Shannon- Wiener	1.419	1.61	2.094	2.561	1.256	0.963

PLATE III



a. Map showing the bloom area from Calicut to Tellicherry –Shaded regions indicate the extent of the bloom

● Sampling sites

b. The muddy green coloured bloom of *Chattonella marina* at Kappad included *C.asteromphalus* at a density of $8x10^4$ cells l^{-1}, *P.normani* at $2x10^4$ cells l^{-1} and *N. sigma* at a density of $4x10^4$ cells l^{-1}. By the eighth day, density of *C.marina* had decreased considerably to 4234 cells l^{-1}. *C.asteromphalus* (1312 cells l^{-1}), *P.normani* (22 cells l^{-1}) and *N. sigma* (552 cells l^{-1}) were the other species of phytoplankton present. By the 22nd day, the density of the harmful algae had reduced to 2200 cells l^{-1}. The density of *C.asteromphalus* had increased to 38,400 cells l^{-1}, *P.normanii* to 164 cells l^{-1} and *N.sigma* to 235 cells l^{-1}. High Chlorophyll *a, b* and *c* values of 12.44, 0.469 and 3.06 mg m^{-3} were recorded at Kappad on the first day. Chl *a* decreased to 5.63 and Chl *c* to 0.72 mg m^{-3} by the 8th day while there was an increase of Chl *b* from 0.469 to 0.65 mg m^{-3}. The sampling on the 22nd day recorded a further increase for Chl *a* and *c* to 30.1 and 4.18 mg m^{-3} while Chl *b* was absent.

Konadu

At Konadu, the density of *C. marina* was very low when compared to that of Kappad. On the first day *C.marina* was present at a density of 40,000 cells l^{-1} along with the diatom *C.asteromphalus* at a density of 8100 cells l^{-1} and *N.sigma* at 120 cells l^{-1}. By the eighth day the density of harmful algae had decreased sharply to 2815 cells l^{-1} while the diatom *C.asteromphalus* increased to a density of 13,200 cells l^{-1}. *P.normani* at a density of 1350 cells l^{-1} and *N.sigma* at 5500 cells l^{-1} were the other diatoms present. On the 22nd day *C.marina* was present at very low densities of 480 cells l^{-1}. The density of *C.asteromphalus* had increased to 45600 cells l^{-1}, *P.normani* to 1730 cells l^{-1} and *N.sigma* to 12,500 cells l^{-1}. High Chl *a* and *c* values of 21.62 and 2.54 mg/m^3 were recorded on the first day which sharply decreased to 1.04 and 0.848 mg m^{-3} by the 8th day, while chlorophyll *b* increased from 0.34 to 0.56 mg m^{-3}. The last day showed an increase in values to 12.6, 1.3 and 1.92 mg m^{-3} for Chl *a, b* and *c*.

Chombala

C. marina was not present at Chombala in the first week. By the second week *C.marina* bloom was noticed at the site and phytoplankton analysis showed that it was present at a high density of 1,70,000 cells l^{-1} at the station. The harmful alga *N.scintillans* was also detected at a density of 100 cells l^{-1}. *C.asteromphalus* at a density of 24700 cells l^{-1}, *P.normani* at a density of 2300 cells l^{-1} and *N.sigma* at a density of 8100 cells l^{-1} were the other algae present. Sampling on the 14th day showed that the concentration of the harmful algae had decreased to 2990 cells l^{-1}, *N.scintillans* to 60 cells l^{-1} and that of *C.asteromphalus* to 2800 cellsl^{-1} at the site. *P.normanii* and *N.sigma* were also present in the sample, but at very low densities. The regular sampling at the station in the next month found the harmful algae to be absent. Chl *a, b* and *c* recorded values of 19.92, 1.364 and 4.92 mg m^{-3} in the first sampling. Higher values of 72.06 mg m^{-3} for Chl *a* and

10.09 mg m^{-3} for Chl *c* was recorded in the next sampling. Chl *b* was absent. The percentage composition of major phytoplankton groups present at these sites during the bloom has been compared with the phytoplankton present at Konadu, Chombala and Kappad during and after the bloom is given in Fig. 2.2.a , b and c. respectively.

Environmental variations

The results of the environmental parameters measured at the three sites is given in Table.2.3. The variation in the major influencing parameters, salinity and temperatures at the three sites is presented in Fig. 2.3a, b and c.

Konadu

The atmospheric temperature increased from an average value of 27°C in August to 29.7°C in September while the SST showed a rise from 27°C to an average value of 29.1°C for the 3 samplings. Salinity also showed an increase from 32 ppt in August to 34 and 35 ppt on the 1st and 8th day and decreased to 31 ppt on the 22nd day. The pH value was low, 7.14 during the exponential phase which increased to 7.6 in the subsequent samplings. BOD values were high which decreased from 12.2 to 7.5 and then to 3.5 mg l^{-1} with the decline of the bloom. Of the nutrients, ammonia concentration was highest with a value of 5.6 μmol l^{-1} which decreased to 1.90 on the 1st and increased to 5.71 μmol l^{-1} in the third sampling. Phosphate, nitrate and nitrite concentrations were very low with a value of 0.03 μmol l^{-1} for all the three nutrients on the 1st day. Phosphate concentration increased to a value of 1.41 μmol l^{-1} by the 14th day. Nitrate and nitrite increased to 0.06 in the second sampling and decreased again to a value of 0.03 μmol l^{-1} by the last sampling.

Chombala

The atmospheric temperature rose from 27 to 29^{0}C while SST increased from 27 to an average value of 29.6^{0}C on the 8th and 22nd day. Salinity at Chombala showed a slight increase from a value of 32 ppt in August to 33 ppt in the first sampling which decreased to 30 ppt in the next. pH which was low, 7.05 in the 8th day increased to 7.68 on the 22nd day. Similar to other stations, the dissolved oxygen content during the bloom period was low of 1.92 which increased to 3.52 mg l^{-1} on the 22nd day. By October, the values had increased to 5.7 mg l^{-1}. TSS recorded a value of 8.5 mg l^{-1} on the 8th day which decreased to 4.6 mg l^{-1} by the next. Ammonia, phosphate, nitrate and nitrite values decreased from 0.34, 2.99, 3.50 in August to 0, 2.76, 0.11 and 0.02 on the first sampling to 2.43, 7.02,1.6 and 0.03μmol l^{-1} on the second sampling.

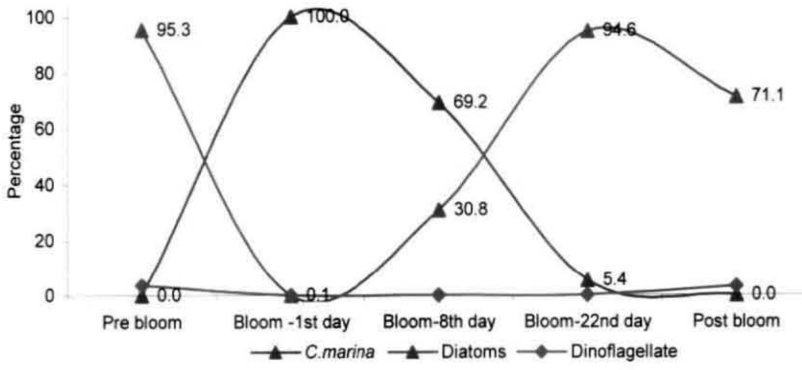


Fig.2.2.a

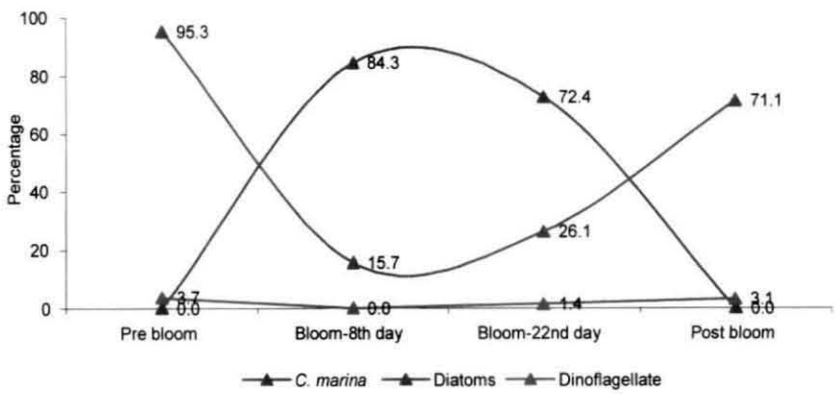


Fig.2.2b

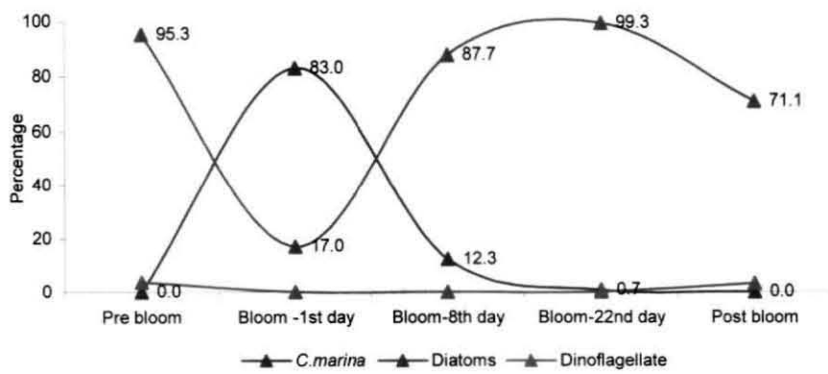


Fig.2.2c

Fig. 2.2. Percentage composition of major phytoplankton groups at (a) Konadu (b) Chombala and (c) Kappad, during the bloom period of *C.marina* compared with pre and post-bloom period

Kappad

The atmospheric temperature had shown an increase from 27° C in August to 29.7° C in September. Both the AT and SST averaged between 30-31° C at Kappad. Salinity also registered an increase from 32 ppt recorded in August to 36 ppt on the first day which decreased to 33 and 30 ppt on the 8th and 22nd day. The pH value was very low of 7.06 on the 1st day which increased to 8.33 and then again decreased to 7.53 on the 8th and 22nd day. A very low dissolved oxygen value of 0.22 mg l^{-1} was recorded on the 1st day which slightly increased to 1.66 and 1.86 mg l^{-1} on the 8th and 22nd day. The TSS content was also high with a value of 33.44 mg l^{-1} in the first sampling and decreased to 5.3 and 4.6 mg l^{-1} thereafter. BOD values did not show much variation and a comparatively high value of 2.9 mg l^{-1} was recorded on the 22nd day. Of the major nutrients, ammonia and nitrate decreased from 0.51 and 0.14 to 0 and 0.04 which then increased to 0.39 and 1.79 μmol l^{-1} respectively. On the other hand phosphate showed a steady decline from 2.99 to 2.45 and to 0.65 μmol l^{-1}. Nitrite values were high in the month preceding the bloom with a concentration of 0.21 μmol $l^{-1}$and was low and did not show much variation during this period.

Impacts

Mass mortality of fishes was observed in the region between Puthiyappa and Kappad. Fishes were killed and were washed ashore all along the shore between these two stations. (Pl. IVa) All the fishes which suffered mortality due to the bloom were demersal. Eels formed a major percentage of the dead fish followed by sciaenids and croakers. Major fishes which were killed included *Epinephelus* sp, *Otolithes* sp, *Cynoglossus* sp and *Johnius* sp. Subsequent to this, mass mortality of green mussels of the region was also observed (Pl. IVb). Besides fishes and mussels, the mole crab *Emerita* sp was also found to be severely affected and these were found washed ashore all along the Kappad beach on 4/9/02. At Chombala, the shells of the bivalve *Mactra violacea* with decayed meat was found washed ashore in large numbers on 13/9/02. Water, bivalve and fish samples from the bloom region were analysed at CIFT for the presence of a biotoxin. The mouse bioassay revealed the presence of a lipid soluble toxin in the water sample from all the three stations. The fish and bivalve samples did not show any toxin in them. The fishery of the region faced a serious set back due to the red tide. Almost all country crafts cancelled operations. Only some multiday trawl netters went for fishing. The impact to the fishery of the region was studied and the results are presented and discussed in detail in Chapter 3.

Table. 2.3. Environmental parameters, cell density and diversity indices during the bloom of *Chattonella marina* at the three sampling sites along Calicut coast

		Kappad			**Konadu**			**Chombala**		
	PRE BLOOM	BLOOM			BLOOM			BLOOM		POST BLOOM
Sampling day		1st	8th	22nd	1st	8th	22nd	8th	22 nd	
SST (^{0}C)	27	30.2	30.8	30.2	29.8	29.4	28.1	29.7	29.5	32
Salinity (ppt)	32	36	33	30	34	35	31	33	30	32
C.marina (cells l^{-1})	0	280000000	4234	2200	40000	2815	480	170000	7166	0
pH	7.9	7.06	8.33	7.5	7.14	7.61	7.6	7.05	7.68	8.22
Dissolved Oxygen (mg l^{-1})	3.99	0.22	1.66	1.86	0.23	2.83	4.34	1.92	3.52	5.7
TSS (mg l^{-1})	50.2	33.4	5.3	4.6	22.5	16.4	4.8	8.5	4.6	2.9
Chl a (mg/ m^3)	148.23	12.44	5.63	30.1	21.62	1.04	12.6	19.92	72.06	12.22
Chl b (mg/ m^3)	20.15	0.469	0.65	0	0.34	0.56	1.3	1.364	0	0.962
Chl c (mg/ m^3)	1.854	3.06	0.72	4.18	2.54	0.848	1.92	4.92	10.09	2.33
Ammonia (µmol l^{-1})	0.34	0.51	0.00	0.39	5.60	1.90	5.71	0	2.43	0.26
Nitrate (µmol l^{-1})	3.50	0.14	0.04	1.79	0.03	0.06	0.03	0.11	1.6	0.07
Nitrite (µmol l^{-1})	0.21	0.02	0.03	0.02	0.03	0.06	0.03	0.02	0.03	.
Dissolved inorganic Nitrogen (DIN) (µmol l^{1})	4.05	0.67	0.07	2.20	5.66	2.02	5.77	0.13	4.06	0.33
Phosphate (DIP) (µmol l^{-1})	2.99	2.99	2.45	0.65	0.03	0.03	1.41	2.76	7.02	0.27
N:P	1.35	0.22	0.03	3.38	188.67	67.33	4.09	0.05	0.58	1.22

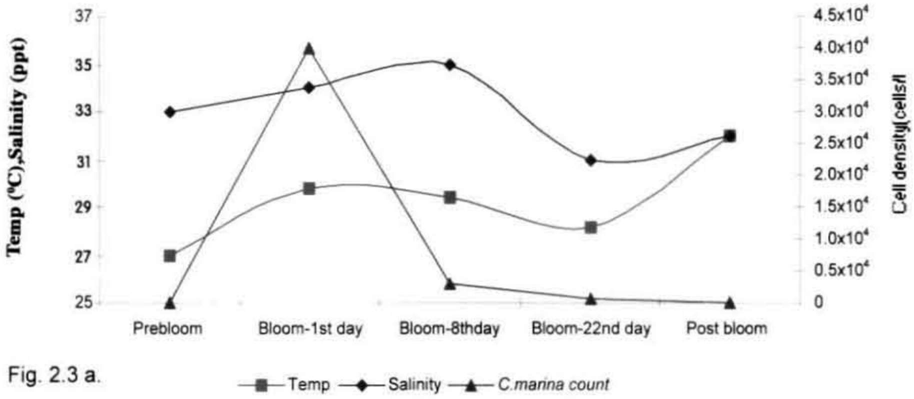


Fig. 2.3 a.

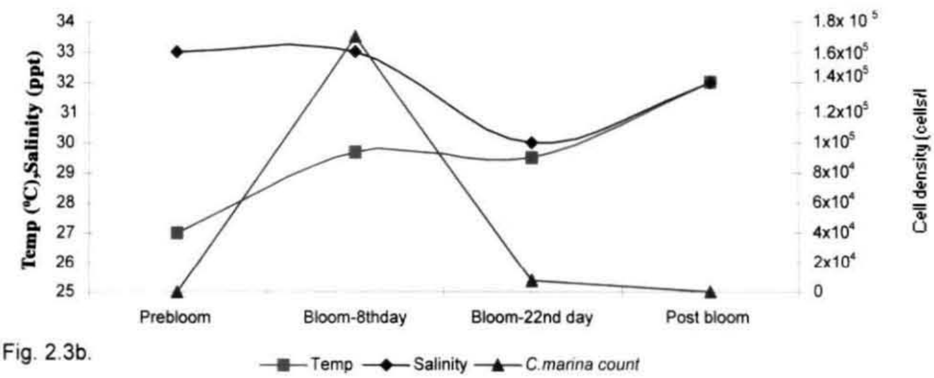


Fig. 2.3b.

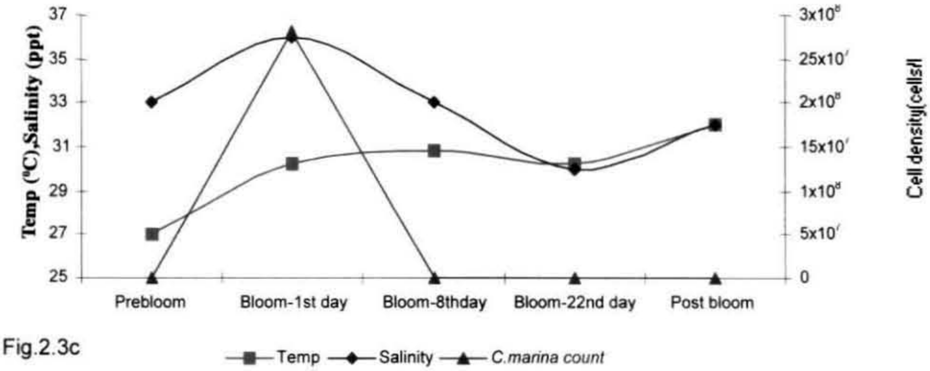


Fig.2.3c

Fig. 2.3. Variation in temperature and salinity at (a) Konadu (b) Chombala and (c) Kappad, with the progress of the bloom

PLATE. IV

a. Mass mortality of fishes along Puthiyappa beach due to the bloom of *Chattonella marina*

b. Mass mortality of green mussels along Puthiyangadi beach due to the bloom of *Chattonella marina*

2.3.2. SOUTH KERALA

I. VIZHINJAM

2.3.2.1. RECORD OF TOXIC ALGAL SPECIES

The toxic and harmful bloom forming species *Noctiluca scintillans* (Macartney) Kofoid and Sweezy 1921, *Prorocentrum micans* Ehrenberg 1833, *Dinophysis caudata* Saville-Kent 1881, *Dinophysis acuminata* Claparede and Lachmann 1859, *Dinophysis miles* Cleve, *Pseudo-nitzschia* sp H. Pergallo, *Pseudo-nitzschia pungens* (Grunow ex Cleve) Hasle, *Trichodesmium* sp and *Ceratium fusus* were recorded from the station and the months of occurrence of these harmful algae at Vizhinjam bay and sea is presented in Fig. 2.4.

A. DINOFLAGELLATES

I. *Dinophysis* spp

The genus was represented by *D. caudata, D. acuminata* and *D miles* at Vizhinjam. The classification, cell structure and toxicity of *D.caudata* and *D.acuminata* has been described in detail in 2.3.1.1. The structure of a member of the same genus which was present only at Vizhinjam is given below.

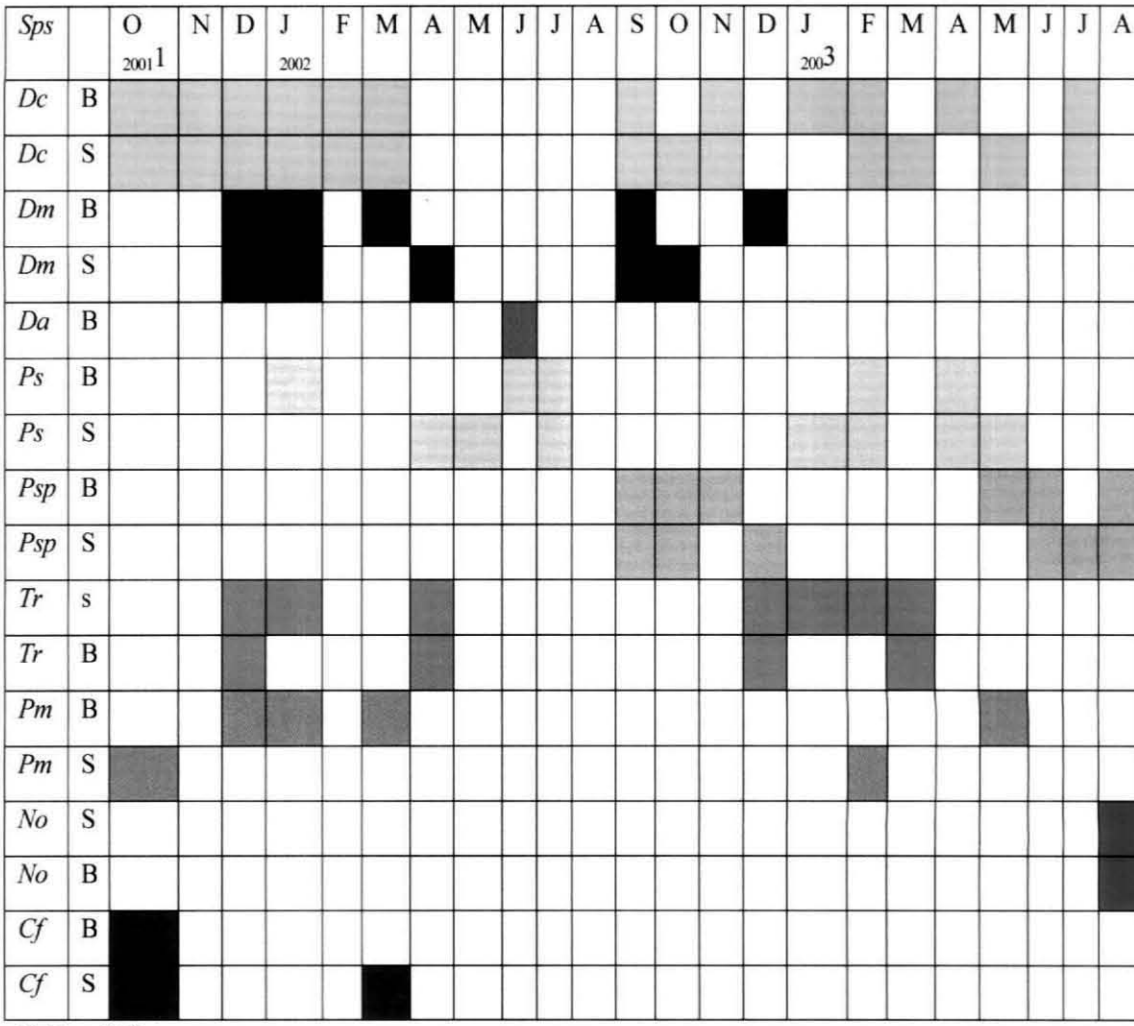
***Dinophysis miles* Cleve**

Cells very large, anterioro-posteriorly elongated with two fairly distinctive long antapical and dorsal projections. Ventral side of the hypotheca undulate. Dorsal side concave and smoothly continues to the dorsal projection which runs obliquely backwards. The distal end bents at right angle carrying a wing like unabsorbed remnant of the megacytic zone. Six to eight daughter cells often attach to the remnant after asexual cell division. Posterior projection shorter or longer than or as long as the dorsal process. Angle between the dorsal and the posterior projection 50 to 90^0. It starts at the base of the third rib. Anterior cingular list wide, supported by many ribs, forming a narrow funnel like structure with very low epitheca on the bottom. Thecal plates thick, round or angular, areolated. Length 125-150 µm (Pl. Vb).

Occurrence

Dinophysis caudata, a dinoflagellate suspected to cause DSP was the harmful algal species, which occurred in most of the sampled months. *D.caudata* was present in the both bay and in the sea in the months of October, December 2001, January to March and again in September, November 2002 and in February and July 2003. The species formed a very low percentage of the phytoplankton sample in most of the months except in December 2001 where it formed a higher percentage of 23% and in March 2002 at a higher percentage of 14.8. *D.caudata* was detected in Nov 2001, January and April 2003 in the Bay alone and October March and May 2002 in the sea alone.

Fig. 2.4. Representation of the months of occurrence of harmful algae at both Vizhinjam bay and sea from October 2001 to August 2003.



B-Bay, S-Sea.

	Dinopphysis caudata (Dc)
	Dinophysis miles (Dm)
	Dinophysis acuminata (Dm)
	Pseudo-nitzschia pungens(Psp)
	Pseudo-nitzschia spp(Ps)

	Trichodesmium (Tr)
	Prorocentrum micans (Pm)
	Noctiluca scintillans (Ns)
	Ceratium fusus (Cf)

In October 2002 a heavy bloom of phytoplankton was observed at the station and *D.caudata* was also present at a higher density of 2800 cells l^{-1}.

D.miles another member of the same genera and suspected to cause DSP was detected both in the bay and sea in December 2001, January, March, April and Sept 2002. In addition, *D.miles* was present in the sample in September 2002 but was absent in the bay. *D acuminata* suspected to cause DSP was detected once in June 2002 in the bay but at a very low percentage.

II. *Prorocentrum micans* Ehrenberg

The classification, cell structure and toxicity of *P.micans* has been described in detail in 2.3.1.1.

Occurrence

P micans a harmful alga was found in separate instances in the bay and at sea. It was detected in October 2001 and January 2002 in the sea and in December 2001 and March 2002 in the bay.

III. *Noctiluca scintillans* (Macartney) Ehrenberg

The classification, cell structure and toxicity of *N.scintillans* have been described in detail in 2.3.1.1. (Pl. Ib).

Occurrence

Noctiluca scintillans was present at a density of 1,02,000 cellsl^{-1} in the sea and 55,000 cells l^{-1} in the bay.

IV. *Ceratium fusus* (Ehrenberg) Dujardin

Classification and Cell structure

Division:	Pyrrophyta
Class:	Dinophyceae
Order:	Gonyaulacales
Family:	Ceratiaceae
Genus:	Ceratium

Large fusiform cell with a fully developed apical horn, a fully developed left hypothecal horn, and a rudimentary right hypothecal horn. Left horn slightly curved to straight. Epitheca tapers gently into slightly curved apical horn. Surface with linear markings (Pl.Va).

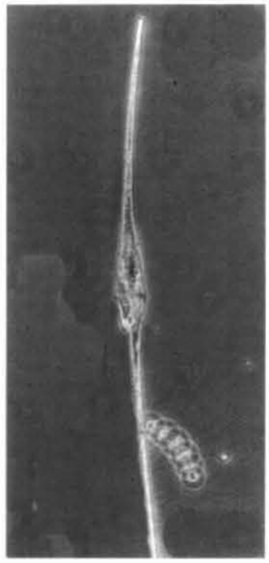
Occurrence

Ceratium fusus was detected in low concentration in October 2001 at both sea and bay and in March 2002 in the sea.

Toxicity

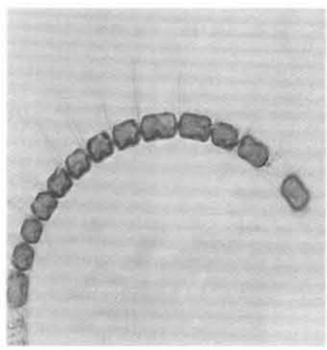
Causes mortality of invertebrate larvae by an unknown mechanism.

PLATE V

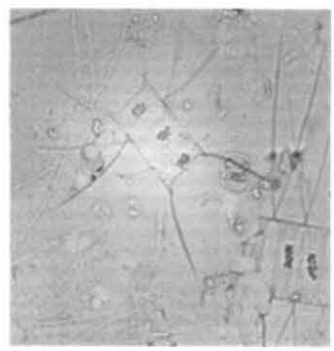


a.

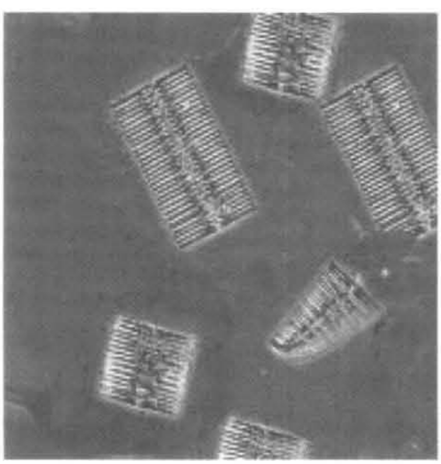
b.



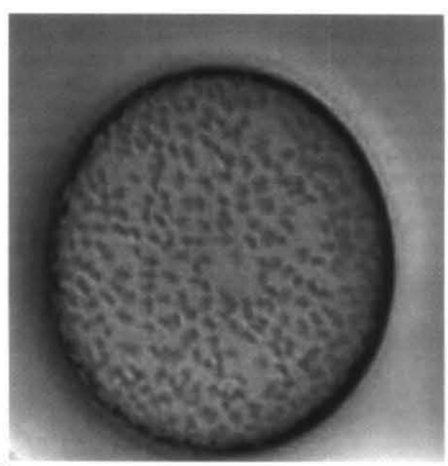
c.



d.



e.



f.

a. *Ceratium fusus* (x 40 x)
b. *Dinophysis miles* (x 40 x)
c. *Chaetoceros curvisetus* (x 40 x)
d. *Chaetoceros eibeini* (x 40 x)
e. *Fragilaria oceanica* (x 40 x)
f. *Coscinodiscus sublineatus* (x 10 x)

B. DIATOMS

I. *Pseudo-nitzschia* spp

The classification, cell structure and toxicity of *Pseudo-nitzschia* and *Pseudo-nitzschia pungens* has been described in detail in 2.3.1.1.

Occurrence

Pseudo-nitzschia was detected in more instances at sea than in the bay. In the sea its presence was recorded in the months of April, May, July October 2002 and again in April and May 2003. In the bay it was present in June, July, October and April 2003. Its density was high in October 2002 when a density of 14,000 cells l^{-1} was recorded in the sea and 92,000 cells l^{-1} in the bay. *Pseudo-nitzschia pungens* another algae suspected to cause ASP was present in Sept 2002, June and July 2003 in the sea and in May, June and August 2003 in the bay. *Pseudo-nitzschia pungens* was the dominant phytoplankton in the region in June with 43% of the total phytoplankton being constituted by this species in the sea and 48% in the bay.

C. CYANOPHYTA

II. Trichodesmium spp

The classification, cell structure and toxicity of *Trichodesmium* has been described in detail in 2.3.1.1. *Trichodesmium* was present in both bay and sea in December 2001 and April 2002. It formed 20.83 % of the phytoplankton community in the bay in April. The alga was present in the sample in January 2002 also.

2.3.2.2. NON TOXIC BLOOMS

Non toxic phytoplankton was found in increased densities at the station in the months of May, June, August, September and October 2002 and in August 2003. The most common bloom forming phytoplankton was the centric diatom *Chaetoceros curvisetus.*

I. *Chaetoceros* Blooms

a. Phytoplankton characteristics

Chaetoceros, which was one of the most dominant genus of the phytoplankton community at Vizhinjam, formed blooms mainly between the late monsoon and the early post-monsoon months at the station. In May 2002 *C.curvisetus* (Pl. Vc) was present at a high density of 1.45×10^7 cells l^{-1} in the sea and at a density of 1.82×10^7 cells l^{-1} in the bay. The species dominated the phytoplankton community with almost 72.6% of the total count at sea being contributed by this species alone and 88.6% in the bay. The diversity and evenness were low with values of 0.476 and 0.343 in the bay and 1.146 and 0.413 in the sea.

Chaetoceros curvisetus bloom was succeeded by the bloom of a diatom of the same genus, *Chaetoceros eibeini* (Pl.Vd). *C.eibeini* was present at a density of 8.2×10^6 cells l^{-1} at sea and at a density of 8.5×10^6 cells l^{-1} in the bay. Evenness values were lower in the bay and sea with values of 0.497 and 0.621 respectively. The diversity recorded was also lower than that recorded for non bloom months with values of 1.489 and 1.365 respectively. A mixed bloom of *Chaetoceros* spp occurred in October with *C.curvisetus*, the dominant member reaching high densities of 70×10^5 cells l^{-1} in the sea and 84×10^5 cells l^{-1} in the bay. *C. affinis* and *C. decipens* were present at densities of 1.2×10^4 cells l^{-1} and 8×10^4 cells l^{-1} in the sea. In the bay *C. affinis* and *C. wighami* were present at a density of 12×10^4 cells l^{-1} each and *Pseudo-nitzschia* sp at a density of 92×10^3 cells l^{-1}. The phytoplankton composition during the bloom period is represented in Fig. 2.5a and b. As the total phytoplankton density at the station this month was contributed by more species, the diversity and evenness values were higher when compared to other bloom months but was comparatively lower than that of non bloom periods. Diversity and evenness values were 1.734 and 0.657 in the bay while lower values of 1.715 and 0.563 was recorded in the sea.

In the next year in the same period the percentage of *C.curvisetus* was higher at the station but reached bloom proportions only in August. In August 2003 another mixed bloom occurred at the station with *C.curvisetus* reaching a density of 1×10^5 cells l^{-1} and *C.decipiens* 1.52×10^5 cells l^{-1}. The harmful alga *Noctiluca scintillans* was also present at a density of 1,02,000 cells l^{-1}. In the bay, *C.curvisetus* was present at a density of 2.35×10^5 cells l^{-1} and *Noctiluca scintillans* at a density of 55,000 cells l^{-1}. *F.oceanica* and *T.nitzschioides* were the other dominant members of the community in August with densities of 45,250 and 71,000 cells l^{-1} in the bay and 52,000 and 8,00,000 cells l^{-1} in the sea. The phytoplankton composition during the bloom period is given in Fig. 2.6a and b. The evenness and diversity values at both the stations were high when compared to other non bloom periods with values of 0.795 and 2.702 in the bay and 0.784 and 1.947 in the sea.

The productivity was highest in October with values of 5.17 and 3.55 $gC/m^3/day$ in the sea. The productivity of the bay was also high of 3.86 and 1.88 $gC/m^3/day$. A bloom of the same species in May 2002 earlier, recorded comparatively lower values of 1.628 and 0.814 in the sea and 1.286 and 1.068 $gC/m^3/day$ in the bay. The bloom of *Chaetoceros* the next year in August also recorded high value of 2.25 and 1.09 $gC/m^3/day$ in the sea and value of 2.21 and 1.07 $gC/m^3/day$ in the bay. Bloom of the diatom of the same family *C.eibeini* recorded high productivity of 2.85 and 2.44 in the sea and 2.04 $gC/m^3/day$ and 1.221 $gC/m^3/day$ in the bay. Chlorophyll values were high in the bay in October during the bloom of *Chaetoceros* spp with values of 35.86 and 1.8 mg/m^3 Chl *a* and *b*. The sea recorded low values of 3.91 mg m^{-3} for Chl *a* in October. Chl *a, b* and *c* at sea was 2.84, 1.3 and 2.59 mg m^{-3} in May, 3.13, 0.27 and 0.345 mg m^{-3} in June, when *Chaetoceros* sp bloomed. Chlorophyll values in the bay in May were lower of 1.46, 0.24 and 0.384 mg m^{-3} while June recorded the same pigment concentration as that of the sea. During the *Chaetoceros* bloom in the following year in August, higher and similar pigment values of 4.9 and 0.82 mg m^{-3} in the sea and bay were recorded while Chl *b* was absent.

Environmental variations

During May, June and October 2002 and in August 2003 when *Chaetoceros* blooms were observed, low atmospheric and sea surface temperatures were recorded. The AT recorded values between 28 and 29^0 C and SST between 27 to 28^0 C. Similar lowering of temperatures was recorded in the bay also, with values of AT between 27-30^0 C and SST between 26 to 29^0 C. Lowest value of 26^0 C was recorded in June during the bloom of the diatom *C.eibeini.* Salinity on the other hand showed an increase from 32 ppt in April to 34 and 35 ppt in May and June when the diatom *Chaetoceros* was present in increased densities at the station. An increase in salinity to 34 ppt in October again followed the bloom of *Chaetoceros* at the station. In the bay, salinities varied between 33 and 35 ppt during the bloom of the species in the first year. In contrast to this, very low salinity value of 25 ppt was noted in both the bay and sea when a mixed phytoplankton bloom dominated by *Chaetoceros* spp occurred in August the following year.

Dissolved oxygen value in the bloom months of May and June were 4.88 mg l^{-1} and 4.34 mg l^{-1} respectively and was higher when compared to a low value of 3.61 mg l^{-1} in April. In the bay, a similar increase in values was observed from a value of 3.87 to 4.07 in May but lowered to 3.80 mg l^{-1} in June. Low values than this were recorded in October with a value of 3.53 in the sea and 2.90 mg l^{-1} in the bay. The TSS value was higher in the bloom period when compared to the non bloom period. TSS value increased slightly from 5 in April to 6.5 mg l^{-1} in May and 4.5 mg l^{-1} in June in the sea. In the bay, still higher values of 8.2 and 4.8 mg l^{-1} were recorded. A similar high TSS value of 12.5 and 12.8 mg l^{-1} was recorded in October in the sea and bay respectively when the diatom *Chaetoceros* sp was present at increased densities. The bloom of the same species in August next year also recorded a higher TSS value of 3.4 mg l^{-1} in the sea and 11.1 mg l^{-1} in the bay. The BOD values did not show major variations but remained at a low value of 0.5 mg l^{-1}. Comparatively higher values of 4.84 in sea and 4.94 mg l^{-1} in the bay was recorded in

August 2003 when *Chaetoceros* sp bloomed but was lesser than that recorded in the previous months.

The variation in nutrient concentration exhibited a different pattern in the bay and sea. The nutrients ammonia, phosphate and nitrate decreased from 1.33, 0.40 and 0.35 $\mu mol\ l^{-1}$ in April to 0.77, 0.7 and 0.14 $\mu mol\ l^{-1}$ in May. An increased concentration of 5.20, 0.67 and 0.46- $\mu mol\ l^{-1}$ was recorded in the next month followed by a bloom of *Chaetoceros* sp in the region which decreased to lower values in July. In October low values of 0.006, 0.003 and 0 $\mu mol\ l^{-1}$ was obtained for these nutrients. The concentration of nitrite showed a reverse trend. Nitrite, which was absent in April, increased to 1.71 $\mu mol\ l^{-1}$ in May accompanied by *Chaetoceros* bloom and a low value of 0.02 $\mu\ mol\ l^{-1}$ was recorded in June. Higher values of 2.21 $\mu mol\ l^{-1}$ was recorded in August and reached the lowest value of 0.097 $\mu mol\ l^{-1}$ in October following blooms in the previous months.

In the bay region, the concentration of all the nutrients were higher in May when compared to that of the previous months. The concentration of ammonia, phosphate, nitrate and nitrite was 10.44, 0.40, 0.53 and 0.71 $\mu mol\ l^{-1}$ in May. It decreased in June except that of phosphate which recorded a comparatively high value of 1.41 $\mu mol\ l^{-1}$. The concentration of nutrients again started increasing, reaching the highest value of 12.40, 2.5, 2.84 and 3.52 $\mu mol\ l^{-1}$ in August. The blooms in August and September decreased the nutrient concentration to the lowest value of 0.02, 0, 0.08 and 0.11 $\mu mol\ l^{-1}$ in October. The major physicochemical parameters during the bloom of *Chaetoceros* spp is presented in Table.2.4.

II. *Fragilaria oceanica* Cleve

Phytoplankton characteristics

In August 2002, the bloom of the pennate diatom *Fragilaria oceanica* (Pl. Ve) was observed at the station. It was present at a density of 4.6×10^5 cells l^{-1} at sea and 4.98×10^5 cells l^{-1} in the bay. Increased densities for the centric diatom *Coscinodiscus sublineatus* was also recorded with cell density of 56, 250 cells l^{-1} in the sea and 70,000 cells l^{-1} in the bay. Evenness and diversity values were low in the sea than at bay with a value of 0.340 and 0.963 in the sea and 0.476 and 1.256 in the bay. The phytoplankton composition in the bay and sea during this mixed bloom period is given in Fig.2.7. a and b. The GP and NP was 2.36 and 1.46 in the sea and 2.91 and 2.42 $gC/m^3/day$ in the bay. Chl *a, b, c* and carotenoid values of 3.58, 0, 0.134 and 0.107 were recorded in the sea and 3.7, 0, 0.325 and 0.099 $mg\ m^{-3}$ in the bay.

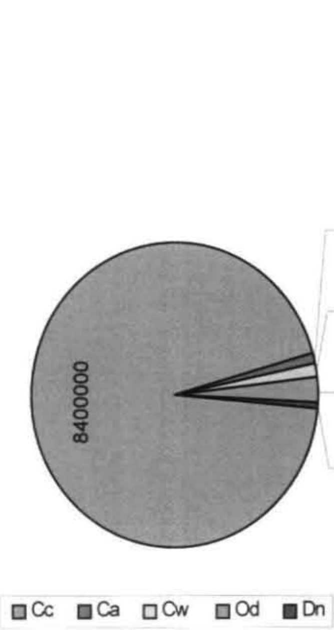


Fig. 2.5.a

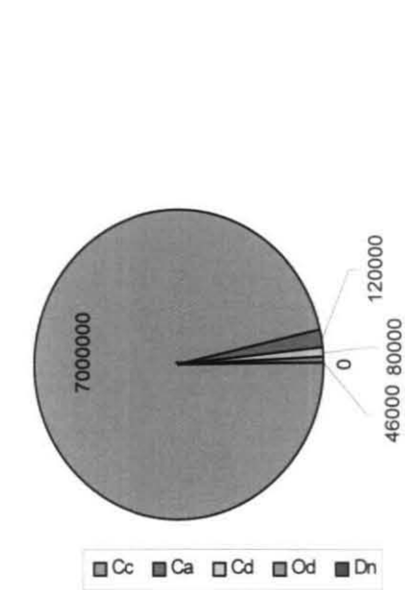


Fig. 2.5. b.

Fig.2.5. Phytoplankton composition and cell density (cells/l) during the bloom of *Chaetoceros curvisetus* in (a) Bay (b) Sea in October 2002.

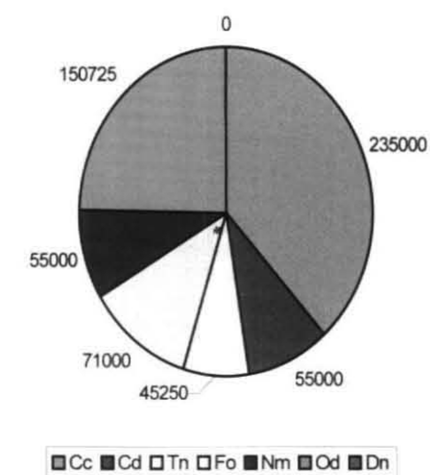


Fig. 2.6.a

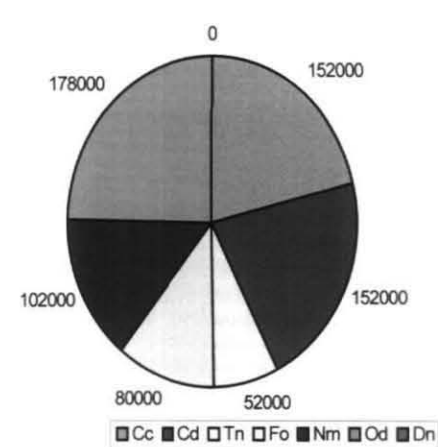


Fig.2.6. b

Fig. 2.6. Phytoplankton composition and cell density (cells/l) during the bloom of *Chaetoceros curvisetus* in (a) Bay (b) Sea in August 2003.

Cc-*Chaetoceros curvisetus*	Cw- *Chaetoceros wighami*	Tf- *Thallassiothrix frauenfeldii*
Ca-*Chaetoceros affinis*	Fo- *Fragilaria oceanica*	Od- Other diatoms
Ns- *Noctiluca scintillans*	Cd- *Chaetoceros diversus*	Dn -Dinoflagellates

Table. 2.4. Environmental parameters, cell density and diversity indices during the bloom of the diatom *Chaetoceros* spp at Vizhinjam

Station	Bay	Sea	Bay	Sea	Bay	Sea	Bay	Sea
Species	*C.curvisetus*	*C.curvisetus*	*C.eibeini*	*C.eibeini*	*C.curvisetus*	*C.curvisetus*	*C.curvisetus*	*C.curvisetus*
Period of occurrence	May 2002	May 2002	June 2002	June 2002	October 2002	October 2002	August 2003	August 2003
Cell density (cells l^{-1})	18200000	14500000	8500000	8200000	8400000	7000000	235000	100000
At.T (^{o}C)	30	29	27	29	28	28	29	29
SST (^{o}C)	28	28	26	27	28	28	28.5	27
Salinity (ppt)	34	34	35	35	33	34	25	25
pH	8.28	8.34	7.94	7.99	8.14	8.24	7.98	8.1
Dissolved oxygen (mg/l)	4.07	4.88	3.8	4.34	2.9	3.53	4.94	4.84
Total suspended solids (mg/l)	8.2	6.5	4.8	4.5	12.8	12.5	11.1	3.4
Biochemical oxygen demand (mg/l)	0.8	0.7	0.6	0.5	1.5	0.8	0.5	0.5
Ammonia (μ mol l^{-1})	10.44	0.77	0.55	5.2	0.02	0.006	6.4	1.1
Nitrate (μ mol l^{-1})	0.53	0.14	0.33	0.49	0.08	0	4.57	17.55
Nitrite (μ mol l^{-1})	0.71	1.71	0.45	0.03	0.11	0.097	6.16	0.403
N:P	29.20	9.70	0.94	8.54	0.00	34.33	100.76	34.64
Dissolved inorganic nitrogen (DIN) (μ mol l^{-1})	11.68	2.62	1.33	5.72	0.21	0.10	17.13	19.05
Phosphate(DIP) (μ mol l^{-1})	0.4	0.27	1.41	0.67	0	0.003	0.17	0.55
Rainfall (cm)	296	296	216	216	451	451	96	96
Speceis Number	4	16	20	9	14	21	30	12
Species richness	0.651	3.259	4.127	1.738	2.827	4.394	6.294	2.392
Pileou's evenness	0.343	0.413	0.497	0.621	0.657	0.563	0.795	0.784
Shannon- Wiener	0.476	1.146	1.489	1.365	1.734	1.715	2.702	1.947

Environmental variations

Temperatures were low and was between 28-29° C in the bay and at sea. A salinity value of 32 ppt was recorded in the bay and 33 ppt in the sea. The dissolved oxygen content in the sea was 4.2 mg l^{-1} and that in the bay was 4.85 mg l^{-1}. TSS and BOD values were low at both the stations except a slightly higher total suspended solid content of 4.9 mg l^{-1} in the bay. The nutrient concentrations were high during the bloom of the species with values of 5.11, 2.5, 2.84 and 2.21 µmol l^{-1} for ammonia, phosphate, nitrate and nitrite in the sea and 12.4, 2.5, 2.84 and 3.82 µmol l^{-1} in the bay. The physicochemical parameters measured during the bloom of *F. oceanica* is given in Table. 2.2.

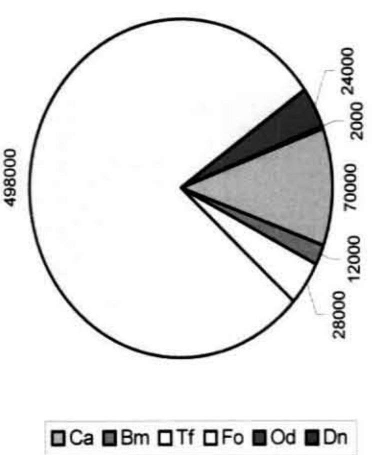
III. Coscinodiscus sublineatus Grunow

Phytoplankton characteristics

In September 2002, increased concentration of the centric diatom *Coscinodisus sublineatus* (Pl.Vf) was present at the station at a concentration of 82,850 cells l^{-1} at sea and 1,28,500 cells l^{-1} in the bay. The diatoms *C.curvisetus* and *C.lorenzianus* were also present at a density of 44,200 and 20,225 cells l^{-1} in the sea and 82,520 and 12,000 cells l^{-1} in the bay. The evenness and diversity was higher when compared to other non-bloom periods with values of 1.637 and 0.620 in the bay and 1.483 and 0.562 in the sea. GP was high with a value of 3.17 and 3.45 gC/m^3/day in the bay and sea while NP was lower with values of 0.998 and 0.886 gc/m^3/day for the two stations. Chlorophyll recorded values of 12.42, 1.24 and 0.028 mg m^{-3} for *a, c* and carotenoids in the sea while Chl *b* was absent. In the bay Chl *c* was absent and Chl *a, b* and carotenoids recorded values of 22.34, 2.48 and 0.19 mg m^{-3} for *a, b* and carotenoids. The phytoplankton composition during the bloom period in bay and sea is given in Fig. 2.8a and b.

Environmental variations

The AT and SST recorded were low with a value of 27° C in the sea and 27 and 28° C in the bay. Salinity was comparatively low than the previous month with a value of 33 ppt in the sea and a still lower value of 31 ppt in the bay. TSS was higher than during other blooms with a value of 10.4 mg l^{-1} in the sea and 14.2 mg l^{-1} in the bay. Nutrient concentration was low with a value of 1.63, 0.66, 0.01 and 1.04 µmol l^{-1}in the sea and 1.96, 0.34, 0.65 and 0.88 µmol l^{-1} in the bay. The physicochemical parameters measured during the bloom of *Coscinodiscus* spp is given in Table.2.1.



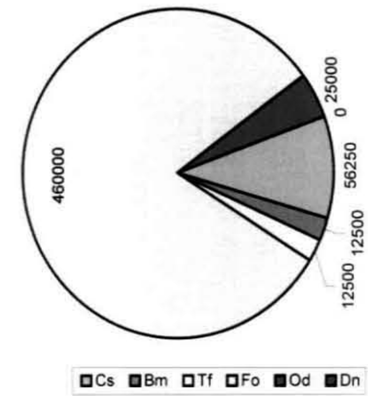
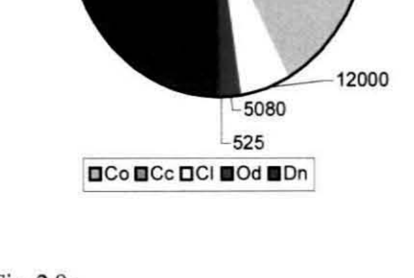


Fig. 2.7a. (b)

Fig. 2.7. Phytoplankton composition and cell density (cells l^{-1}) during the bloom of *Fragilaria oceanica* in (a) Bay (b) Sea in August 2002.



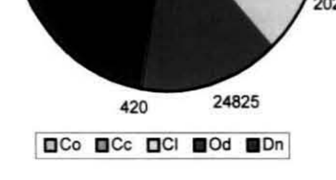


Fig. 2.8a. (b)

Fig. 2.8. Phytoplankton composition and cell density (cells l^{-1}) during the bloom of *Coscinodiscus sublineatus* in (a) Bay (b) sea in September 2003.

Cc-*Chaetoceros curvisetus*	Cl- *Chaetoceros lorenzianusi*	Tf- *Thalassiothrix frauenfeldii*
Ca-*Chaetoceros affinis*	Fo- *Fragilaria oceanica*	Od- Other diatoms
Co-*Coscinodisus sublineatus*	Bm- *Biddulphia mobilensis*	Dn -Dinoflagellates

2.3.2.3. HARMFUL BLOOMS

I. Dinophysis caudata

Dinophysis caudata suspected to cause DSP was present in most of the monthly samples at Vizhinjam. In December 2001 it formed 23.8% of the phytoplankton community at sea and 12.8 % in the bay. In October 2002 when a phytoplankton bloom was observed at the station *D.caudata* was also present at an increased density of 2800 cells l^{-1} in the bay but was absent in the sea. On analysing the abiotic environmental variables it could be observed that both AT and SST was 30°C and the salinity, 31 ppt. The bay also recorded the same temperature but the salinity was slightly higher of 32 ppt. TSS did not show much variation in the bay but recorded a high value of 11.4 mg l^{-1} in the sea. BOD showed higher value of 5.1 mg l^{-1} in the sea. Ammonia and phosphate concentration was higher in December 2001 at both the sites. Ammonia and phosphate which were nil in November showed a concentration of 0.34 and 0.744 in the bay and 0.56 and 0.13 µmol l^{-1} in the sea. Ammonia showed complete depletion while phosphate decreased to 0.07 µmol l^{-1} in the bay and to 0.06 µmol l^{-1} in the sea. Both nitrate and nitrite which were high in the previous months showed complete depletion in the bloom month. Nitrate showed a complete depletion in the sea. Chlorophyll values were same at both bay and sea in November and December. It showed an increase from 0.148 and 0.121 mg/m^3 for Chl *a* and b to 0.427 and 0.72 mg m^{-3} in December while Chl *c* which was present at concentration of 0.212 mg m^{-3} was absent in December.

OCTOBER 2002

The density of *D. caudata* recorded a high value of 2800 cells l^{-1} in the bay during the phytoplankton bloom that occurred in October 2002. The hydrography has been presented in the section of non-toxic blooms.

II. Noctiluca scintillans

Phytoplankton characteristics

The bloom of the harmful dinoflagellate *Noctiluca scintillans* was observed in August 2003 both in the bay and sea (Pl. VIIa). The sea was golden yellow coloured close to the shore with a frothy appearance along the shoreline. *Noctiluca* was present at a density of 1,02,000 cells l^{-1} in the sea and at a lesser density of 55, 000 cells l^{-1} in the bay. An increased density of phytoplankton was observed at the station during this month, which was contributed mainly by the bloom of *C.curvisetus* at the station. Both gross and net productivity values were higher at bay and sea in August than the preceding month. In the sea it increased from 1.93 to 0.99

gC/m^3/day in July to 2.25 and 1.082 gc/m^3/day in August. In the bay, an increase in GP and NP from 2.128 and 1.012 gC/m^3/day to 2.206 and 1.068 gC/m^3/day was observed. Pigment values were higher in the bloom period when compared to June and was the same for both bay and sea. Chl *a* and *c* values were 4.9 and 0.822 mg/m^{3}at both the stations while Chl *b* was absent.

Environmental variations

Both AT and SST showed a decrease from 30 and 28°C in July to 29 and 27 °C in August at Vizhinjam sea. In the bay however the SST showed an increase from 27 to 28.5°C. A sharp decline in salinity from 35 ppt to 25 ppt was recorded in the sea. In the bay, the decline was not very sharp and a decrease from 30 to 25 ppt was noted. pH value showed a decrease from 8.14 to 7.98 in the bay whereas in the sea it showed a slight increase from 8.02 to 8.1. The dissolved oxygen at both the stations were lower than the previous months. It decreased from a value of 5.02 to 4.84 mg l^{-1} in the sea and from 5.22 to 4.94 mg l^{-1} in the bay. TSS did not show any variation in the sea whereas in the bay a higher TSS of 11.1 mg l^{-1} was recorded. At sea, a high nitrate value of 20.9 µmol l^{-1} was recorded in the month preceding the bloom. Both ammonia and nitrate values showed depletion with the bloom. Ammonia values decreased from 2.25 to 1.1 µmol l^{-1} and nitrate from 20.9 to 17.55 µmol l^{-1}. Phosphate and nitrite values were however slightly higher in the bloom months. In the bay, the nitrite values recorded were above the range reported for the entire study period. Ammonia, nitrate and nitrite values decreased from a value of 7.16, 5.39 and 7.27 µmol l^{-1} in July to 6.40, 4.57 and 6.16 µmol l^{-1} in August. Phosphate was however slightly higher of 0.17 µmol l^{-1} in the bloom month when compared to 0.13 µmol l^{-1} the previous months. The major physicochemical parameters during the bloom is given in Table.2.5.

Impacts

No mortality of fish or other fauna was reported from the region. A general avoidance of bloom area by fishes was noted as evidenced by the low fish landings at Vizhinjam from gears operated in the bloom region.

II. THANKASSERY

***Noctiluca scintillans* (Macartney) Kofoid and Sweezy 1921**

In the third week of September 2003, a deep orange colouration was observed in the waters of Thankassery bay with the intensity of the colouration increasing towards the shore line. The water samples on analysis showed the presence of the toxic dinoflagellate *N.scintillans* at a high density of 98,000 cells l^{-1} at the site (Pl. VIIb). The other phytoplankton which were present in the sample were the diatom *Coscinodiscus* sp at a density of 5 cells l^{-1} and *Gyrosigma balticum* at density of 3 cells l^{-1}. A complete exclusion of other phytoplankton was noted. The pigments Chl *a* and *c* showed a value of 1.14 and 0.019 mg m^{-3} in the bloom period while Chl *b* was absent. Chl *a, b* and *c* values were lower in the preceding and succeeding months with values of 0.05, 0.03 and 0.04 mg m^{-3} in August and 0.65, 0 and 0.07 mg m^{-3} in October. Table. 2.5 gives the results of the major physicochemical and biological parameters measured before during and after the bloom.

The atmospheric temperature showed an increase to 28° C from 27° C the previous month. The salinity also showed a higher value of 33 ppt compared to 32 ppt the previous month. pH did not show any variation and recorded a value of 8.1. The TSS showed a slight increase from 24.8 in August to 27.2 mg l^{-1} during the bloom which decreased to 23.9 mg l^{-1} the next month. Of the nutrients, the ammonia concentration was comparatively very higher during the bloom period. Ammonia which was nil in August increased to a value of 14.9 µmol l^{-1} during the bloom period. Phosphate and nitrate values showed a slight increase from 1.24 and 0.06 µmol l^{-1} in August to 1.7 and 0.08 µmol l^{-1} in the bloom period which decreased thereafter. Nitrite however showed depletion from a higher value of 2.10 in August to 0.24 µmol l^{-1} in September which increased to 0.93 the following month.

Impacts

Small fishes could be seen dead and floating on the water surface all along the bay. The pearl oyster suspended in the cages in the CMFRI raft in the bay were severely affected .A mortality rate of 27% was recorded for adult oysters between the size range of 48-60 mm. Green mussels in the raft also suffered heavy mortality. Fishes were reported to avoid the bloom area. The toxin analysis at CIFT did not show the presence of any PSP/DSP toxin in the water and bivalve sample.

2.3.3. CENTRAL KERALA

2.3.3.1. HARMFUL BLOOM

I. *Chattonella marina* Bloom

Phytoplankton characteristics

Chattonella marina which blooms regularly along the Calicut coast bloomed for the first time in the coastal region along Vypin, Cochin in September 2003. The bloom extended to a distance of about 1km from the coastline covering a distance of 3km from Puthuvypin to Malipuram (Plate.VIIIa). The greenish brown coloured bloom was noticed in the second week of August in the coastal waters and adjacent farms of the area (Pl.VIIIb). Bloom subsided in the coastal waters on the third day itself but in nearby fish ponds it remained in the bloom condition till the end of the month. Sampling was done on alternate days, from the day the bloom was observed at sea (19/9/03) till the end of the following month until the normal flora was restored.

PLATE VIII

a. Golden yellow coloured bloom of *Noctiluca scintillans* at Vizhinjam

b. Orange coloured bloom of *Noctiluca scintillans* in Thankassery bay

Table. 2.5. Environmental parameters, cell density and diversity indices during the bloom of the dinoflagellate *Noctiluca scintillans* at Vizhinjam and Thankassery

PARAMETERS	VIZHINJAM		THANKASSERY		
	BAY	SEA	Pre-bloom	Bloom	Post-bloom
Cell density (cells l^{-1})	55000	102000	0	98000	0
Period of occurrence	August 03	August 03	September 03	October 03	
At.T (°C)	29.0	29	27	28	29
SST (°C)	28.5	27	28	29	29
Salinity (ppt)	25.0	25.0	32	33	34
pH	7.98	8.1	8.1	8.1	8.1
DO (mg/l)	4.94	4.84	5.8	4.8	4.9
Total suspended solids (mg/l)	11.10	3.4	24.8	27.2	23.9
Biochemical oxygen demand (mg/l)	0.50	0.5	-	-	-
Ammonia (μmol l^{-1})	6.40	1.1	0	14.9	5.7
Phosphate (μmol l^{-1})	0.17	0.55	1.24	1.7	0.93
Nitrate (μmol l^{-1})	4.57	17.55	0.06	0.08	0.06
Nitrite (μmol l^{-1})	6.16	0.403	2.1	0.24	0.93
Rainfall (cm)	96.00	96.00	-	-	-
Species numbers	30	12	-	6	-
Margalef's Species richness	6.294	2.392	-	1.4	-
Pileous evenness	0.795	0.784	-	0.24	-
Shannon- Wiener	2.702	1.947	-	0.48	-

The phytoplankton collected from the sea was dominated by *C.marina* on the 1st and 3rd day after which the diatom *Coscinodiscus* sp became dominant. Count of *C.marina* on 1st day was 2,40,000 cells l^{-1} which decreased to 17000 cells l^{-1} on the 3rd day and was absent in the subsequent samplings. *Coscinodiscus* sp present at 98 cells l^{-1} on the 1st day, increased to a density of 137 cells l^{-1} by 23rd day. A higher density was noted in the farm when compared to that of sea. The density which was 4,68,000 cells l^{-1} on the 1st day decreased to 40,000 cells l^{-1} by the 3rd day. On the 5th day, it again increased to 2,00,000 cells l^{-1} but there were isolated patches in the ponds which received bright sunlight where *C. marina* had concentrated in very high numbers. By the 7th day, *Peridinium sp* had become dominant whose density increased to 1400 cells l^{-1} by the 23rd day of the bloom. The phytoplankton composition at both the stations are represented in Fig.2.9. Temperature seems to play an important role in the retaining the bloom condition. The variation in phytoplankton densities with temperature is given graphically in Fig. 2.10. The results of the analysis of physicochemical and biological parameters measured at the two sites is given in Table. 2.6. Chl *a, b, c* and carotenoids values were higher at sea in the 1st, 3rd and 5th day and varied between 55.9 and 73.7 mg m^{-3} for Chl *a*, 0 and 23.81 mg/m^3 for Chl *b* and between 5.89 and 21.58 mg m^{-3} for chl c and between 0 and 1.244 mg m^{-3} for carotenoids. On the

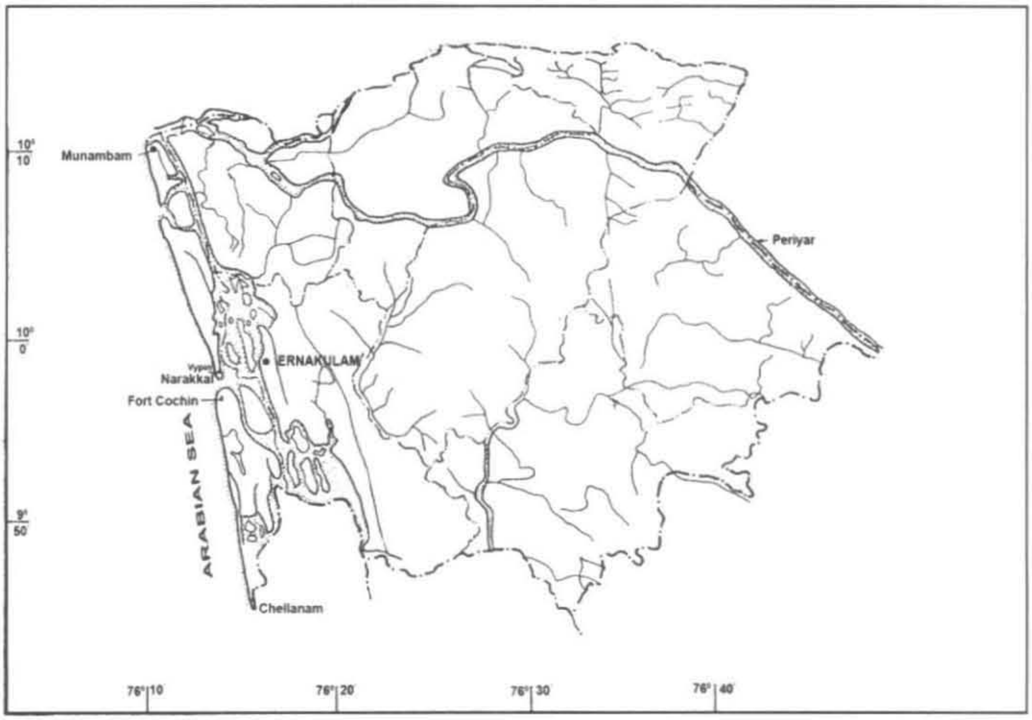
7^{th}, 9^{th} and 23^{rd} day Chl *a* varied between 1.1 to 7.89 mg m^{-3}. Chl *b* at the site varied between 0.61 and 6.13, Chl *c* between 0.36 and 0.381 and carotenoids between 0.019 and 0.14 mg m^{-3}. In the farm site pigment values were comparatively higher through out the bloom period. It varied between 14 and 48 for Chl *a* between 0 and 44.4 for Chl b 3.6 and 16.5 for Chl *c* and 0.07 and 1 mg.m^{-3} for carotenoids. Comparatively higher Chl *a* was recorded on the 3^{rd} and 23 rd day of the bloom. High Chl *b* and *c* of 44.4 and 16.5 mg.m^{-3} was obtained in the 9^{th} day of sampling. Chl *a* and carotenoids were lower of 14.37and 1.01 mg.m^{-3} on this day.

Environmental variations

The air temperature showed a general increasing trend from a low value of 27°C on the 1^{st} day to 32°C on the 23^{rd} day except a decrease from 31.2 to 28.2 °C on the 8^{th} day of bloom. The SST stayed at a value of 29°C except a lower value of 27.3 and 26.2 °C on the 5^{th} and 7^{th} day of the bloom. Compared to sea, the AT and SST in the adjacent farm was higher. The temperature decreased steadily from a high value of 34 °C in the initial to 26°C in the last phase and SST decreased 33 to 30 °C except a high value of 35°C on the 5^{th} day. Salinity varied between 30 and 35 ppt in the sea and between 25 and 27°C in the farm. Dissolved oxygen content was found to increase steadily from a value of 2.06 during the bloom to 4.38 mg l^{-1} when the algae was absent from the phytoplankton community. In the farm the dissolved oxygen value was low in the initial phase and varied between 2.06 to 2.61 mg l^{-1} and between 3.36 to 4.73 in the last phase.

The nutrient content was higher in the farm site when compared to that of the sea. Nitrate and nitrite values were high at sea on the 1^{st} day with values of 4.48 and 0.101 µmol l^{-1} respectively. Comparatively lower values were obtained in the subsequent sampling which varied between 0.05 to 0.84 for nitrate and 0.09 to 0.1 µmol l^{-1} for nitrite. Ammonia values showed a depletion in the first day and increased to 2.57 µmol l^{-1} on the 5^{th} day and thereafter again started decreasing. Phosphate which was low initially increased to values between 1.55, 1.77 and thereafter decreased to values below 0.8 µmol l^{-1}. In the farm the nitrate content of the water was very high, 71.84 µmol l^{-1} on the 1^{st} day. It sharply declined to 0.15 and 0.082 µmol l^{-1} in the subsequent samplings and slightly increased thereafter. Phosphate values showed an increasing trend from 1.44 in the beginning to values between 2.03 and 3.52 µmol l^{-1} in the subsequent samplings. Ammonia values showed frequent fall and rise at the site. It was higher on the 1^{st} and 3^{rd} day with values of 1.56 and 1.42 µmol l^{-1} and varied between 0.5 and 1.38 in the subsequent ones. Nitrite which was slighltly high with a value of 0.157 µmol l^{-1} in the first sampling showed lower values in the subsequent samplings.

PLATE VIII



a. Map showing region of bloom of the rapidophyte *Chattonella marina*

b. *Chattonella marina* bloom in Narakkal farm

Impacts

Heavy mortality of shrimps and fishes were noticed in the shrimp ponds at Narakkal and nearby villages like Valappu, Elakkunnapuzha and Nayaambalam where there was a direct intake of water from the sea. Though *C marina* remained in the bloom condition only for a short period of about three days in the sea, the algae that had entered the coastal farms during tidal exchange remained in the ponds for a longer period which led to mass mortality of fishes and prawns in these ponds. The fishes which were killed were mainly *Chanos chanos, Mugil cephalus and Etroplus maculatus.* Farmers faced heavy financial losses as fishes of all size groups from 100 to 600 mm were killed due to the bloom. Heavy mortality (>90%) of peaneid shrimps like *Penaeus monodon* and *P. indicus* and non penaeid shrimps like *Metapenaues dobsoni* and *M. affinis* were observed. An unusual catch of catfishes were obtained by fishermen during the bloom period. Cat fishes which appeared in large numbers seemed to be in a disoriented condition and so could be easily caught. The fish and water samples were analysed for paralytic and diarrhetic shell fish poisoning at CIFT. The mouse bioassay showed the presence of a lipid soluble toxin.

Table. 2.6. Environmental parameters, cell density and diversity indices during the bloom of *Chattonella marina* at Narakkal

	Day 1		Day 3		Day 6		Day 8		Day 10		Day 23	
	Sea	Farm	Sea	Farm	Sea	Farm	Sea	Farm	Sea	Farm	Sea	Farm
AT (°C)	27	34	29	30	30	31.2	31.2	30.2	28.2	29.3	32	26
SST (°C)	29	33	29	30	27.3	35	26.2	30.3	29	30.3	29	30
Salinity (ppt)	30	26	30	26	35	25	31	27	33	26	34	26
Dissolved oxygen	2.06	2.61	2.12	2.4	2.28	2.06	3.68	4.73	4.12	3.36	4.38	3.88
pH	8.3	8.3	7.96	7.9	7.7	7.5	7.7	7.7	7.8	7.5	8.1	7.6
Ammonia (μmol l^{-1})	0.05	1.56	0.00	1.42	2.57	0.50	0.51	0.78	0.32	1.38	0.24	0.65
Nitrate (μmol l^{-1})	4.48	71.84	0.05	0.15	0.45	0.08	0.84	2.74	0.37	2.24	0.48	2.45
Nitrite (μmol l^{-1})	0.10	0.16	0.08	0.06	0.08	0.09	0.08	0.07	0.11	0.07	0.09	0.11
Phosphate (μmol l^{-1})	0.53	1.44	1.77	2.03	1.55	2.32	0.58	3.52	0.52	2.39	0.82	2.56
N:P	8.7	51.1	0.1	0.8	2.0	0.3	2.4	1.1	1.5	1.5	1.0	1.3
TSS	2.5	4	10.5	48.1	11.3	12.6	10.5	5.2	6.6	16.2	8.5	10.2
BOD	0.5	5.1	1.8	12.3	1.9	5.5	1.3	8.4	2.1	5.8	2.5	2.5
Chl *a* (mg/m^3)	55.94	24.67	64.8	5.4	73.7	13.98	1.1	17.38	2.73	14.34	7.89	40.4
Chl *b* (mg/m^3)	0	4.66	23.81	0	0	1.4	0.613	1.88	6.13	44.4	1.36	0.82
Chl *c* (mg/m^3)	9.33	4.98	21.58	4.33	5.89	4.88	0.358	3.62	3.81	16.55	1.41	13.1
Carotenoids (mg/m^3)	0	0.584	1.244	0.99	1.065	0.069	0.0193	0.44	0.115	1.013	0.142	0.92

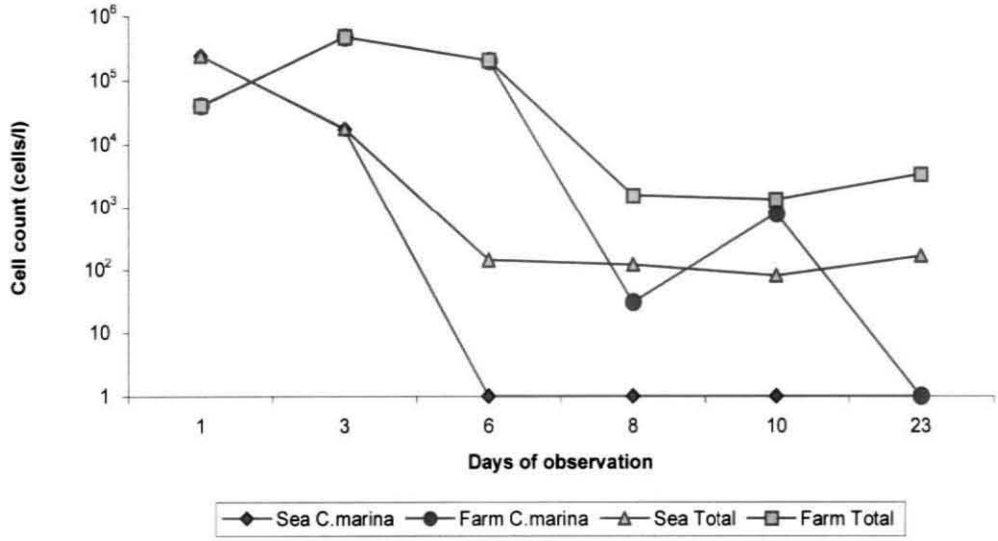


Fig. 2.9. Variation in cell densities of *Chattonella marina* and total phytoplankton in the sea and adjacent shrimp farm after bloom formation along Vypin island.

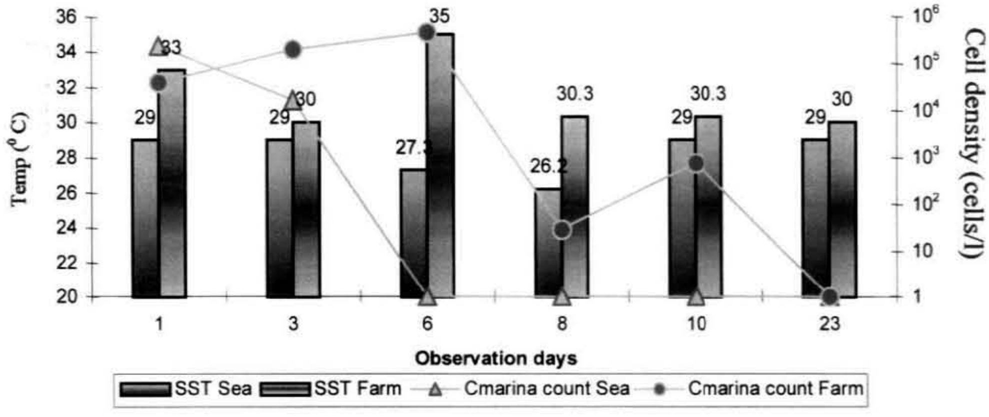


Fig. 2.10. Variation in phytoplankton densities with temperature at the farm and the sea

2.4. DISCUSSION

Phytoplankton bloom dynamics appears to follow a seasonal pattern at both the study sites. According to Svedrup *et al.* (1942) and Raymont (1980), the permanent temperature stratification in tropical and subtropical latitudes spatially separates light and nutrients so that there are no well-defined spring and autumn peaks as described by Cushing (1959) in the temperate and polar latitudes. But a very early and detailed investigation made by Subrahmanyan (1959b) notes that along the west coast, there is a bimodal oscillation in standing crop, with a primary maxima occurring during southwest monsoon period in June-July and secondary maxima in northeast monsoon months between December-April, though with slight variation in the intensity of the bloom and its time of occurrence. Devassy and Bhattathiri (1974) observed maximum density of diatoms in the post-monsoon months, dinoflagellates in pre-monsoon months and other algae in the monsoon months. He observed that the bloom of the diatoms, *Nitzschia sigma* occurred in May with cell numbers of 14,06,400 cells l^{-1}, *S.costatum* at 4,02,400 and 5,03,400 cells l^{-1} in November and December whereas the dinoflagellate *C. furca* at a density of 1,23,000 cells l^{-1} occurred in March and *Peridinium* with a density of 59,100 cells l^{-1} in April. Kumaran and Rao (1975) noted the bloom of *S.costatum* at cell numbers of 2,41,600 cells l^{-1} in June and 3,12,600 cells l^{-1} in September. Gowda *et al.* (2001) also recorded phytoplankton blooms along the Mangalore coast in pre and post-monsoon months. He noted the bloom of the diatom *Cerataulina berganii* in December (47,205 cells m^{-3}) and April (1,23,510 cells m^{-3}) and *Chaetoceros curvisetus* in December (24301 cells m^{-3}). The density of dinoflagellates were comparatively lesser, but were found to be higher in pre-monsoon season when densities reached 3327 cells m^{-3} for *Ceratium furca* in March, 1140 cells m^{-3} for *C. fusus* in January. Jayalaksmi *et al.* (1986) in Cochin backwaters, Edward and Ayyakkannu (1991) in Mulki estuary, Mishra and Panigraphy (1995) in Bahuda estuary and Tiwari and Vijayalakshmi (1999) in Dharmatar creek have all recorded phytoplankton blooms in the pre and post-monsoon period, with blooms in the post-monsoon season caused mainly by diatoms and that in pre-monsoon caused by dinoflagellates. Selvaraj *et al.* (2003) recorded peaks of phytoplankton production in the surfzone and back waters of Cochin during August to January due to occasional blooming of certain species of diatoms. He observed blooming of *P.normanii* in August at a density of 85,000 cells l^{-1}, *Nitzschia sp* in September at 7170 cells l^{-1}, *Synedra* sp in October (26340 cells l^{-1}), *Thalassionema* in October (31000 cells l^{-1}) and *Thalassiosira* in December (57000 cells l^{-1}). At Chombala and Vizhinjam, the bloom of the diatoms were observed between the late pre-monsoon and the early post-monsoon months. The peak time of this spring bloom and its species composition however varied between the years. The bloom of the diatoms was followed by the bloom of the flagellate *Chattonella marina* at Chombala. At Vizhinjam, the bloom of the diatoms was followed by an increase in diversity and density of dinoflagellates. At Chombala, the bloom of centric diatoms mainly *Coscinodiscus* spp was the most frequent in the first year, were as in the second year the blooms were mainly due to the pennate diatoms *Thalassiothrix frauenfeldii*, *Thalassionema nitzschioides* and *Pleurosigma normanii*. At Vizhinjam, *Chaetoceros* spp was the dominant bloom forming species with occasional bloom of *F.oceanica* and *Coscinodiscus sp.* The species diversity was also higher during these period of diatom blooms, which indicate that the conditions are favourable for the development of more number of species and are important for the transfer of energy to higher trophic levels.

Earlier studies have attributed the higher densities during the post-monsoon period to the stability of water, less turbidity and improved light and nutrient conditions. According to Smayda (1997) variation in physical habitat leads to major variations in plankton cycles, ecosystem structure and productivity. At Chombala and Vizhinjam these major changes in physical habitat seems to be strongly influenced by weather driven monsoonal events which leads to variation in temperature, irradiance, precipitation, runoff and nutrient loading, which in turn influence the phytoplankton succession and bloom patterns. A combination of factors seems to influence the bloom dynamics in both the regions of which temperature, salinity and major nutrients seems to be the influential factors deciding the succession pattern of phytoplankton. A study on the abiotic factors leading to the diatom blooms along the southern Californian coast by Tont (1981) finds that diatom bloom follows a decrease in SST and increase in nutrients in the surface layer, which is indicative of upwelling. Lowered temperatures have also been associated with increase in phytoplankton cell numbers in the temperate bay of Iskendrun in the NE Mediterranean sea (Turkoglu and Koray, 2002) and by Polat *et al.* (2002). Subrahmanyan (1959b) attributes the peak in phytoplankton production observed along the west coast which starts from the monsoon months, to the fall in temperature to optimum levels and to a lowering of salinity. According to him, during this period of lowered salinity, cells of those species which have attained their minimum characteristic size, form auxospores and since there is also plenty of nutrients at this time, the phytoplankton utilises it leading to their blooming. As to which species will bloom, depends on species specific requirements of these abiotic factors. Devassy and Bhattathiri (1974) supports the finding that sudden outburst of phytoplankton is followed by lowering of salinity but observes that it occurs at higher temperatures between 29.9 to 32.°C which follows a break in monsoon. Temperature, salinity and nutrients have been identified to be the major reasons for seasonal blooms in the coastal waters of India by Gopinathan, 1974 Qasim *et al.,* 1972 and

Mathew *et al*, 1988 also. Besides, Qasim (1972) also observed that photosynthetic rates of different phytoplankton are higher when salinities were between 10 and 25 ppt. According to Selvaraj *et al.* (2003) the nearshore waters of the west coast are in general, enriched with sufficient quantities of nutrients through out the year, which indicated that the nutrients alone never acted as limiting factors for phytoplankton productivity in these waters. It is more likely that showers of discontinuous rainfall with intermittent gaps, occurring occasionally during pre-monsoon months and more predominantly during southwest monsoon periods resulting in sudden changes of salinity and water temperatures might act as trigger mechanism to induce the blooming of certain species which prefer that particular range of salinity and temperature in the presence of sufficient nutrients in coastal waters and back water environment. He also points out that the studies on phytoplankton blooms done over the years shows that they can occur whenever and wherever adequate light and nutrient conditions for the bloom are coincident.

High irradiance, high nutrients, low temperatures and salinity led to the blooming of *Coscinodiscus asteromphalus* which was the dominant member of the phytoplankton community of the region. The cell densities were the highest when the temperatures were the lowest in August. A nitrogen source seems to be essential for the blooming of this phytoplankton. The dissolved inorganic nitrogen (DIN) was high during the bloom of the species at both the sites and seems to trigger the bloom of the species along with low temperatures and salinity. Also Azov (1986) states that larger phytoplankton species and those with higher nutrient requirement respond faster to favourable conditions and dominate the population at the time of the bloom. Blooming of *Coscinodiscus* sp has been reported from the northern part of the southwest coast of India namely Karwar and from Madras coast (Mathew *et al.*, 1988). The bloom was observed between November to March for the species along the west coast and in April, September, December and January in Madras.

The depletion of nitrate source but an increased concentration of phosphate favoured the bloom of pennate diatoms *Asterionella japonica*, *T. frauenfeldii. T.nitzchioides* and *P. normanii* at Chombala. Mathew *et al.* (1988) also noted bloom of *Thalassionema* in June at Vizhinjam and *Thalassiothrix* in the same month at Madras. Satpathy and Nair (1996) recorded the bloom of the pennate diatom *Asterionella japonica* in the coastal waters of Kalppakkam at a density of 8.5 x 10^{10} cells m^{-3} and along the Waltair coast by Subha Rao (1969) at a density of 90×10^6 cells l^{-1}. For the above pennate diatoms phosphate is the major nutrient which triggered the bloom. According to Lukatelich and McComb (1986), of nitrogen and phosphorous, phosphorous often controls the amount of plant biomass in the system. Thus they have noted in many occasions that there was an abundant supply of nitrate but there was no bloom. Thus even if nitrogen source was in plenty during the monsoon of the second year of study there were no bloom presumably due to a depletion in phosphate concentration and due to very heavy monsoonal rains which resulted in decreased stability.

At Vizhinjam, the concentration of nutrients was comparatively low when compared to that of Chombala. The phytoplankton mainly diatoms bloomed whenever there was a slight increase in nutrients, especially phosphate. *Chaetoceros* spp seems to have a lower requirement for nutrients when compared to other diatoms of the region and bloomed whenever the concentration was a little higher. *Chaetoceros* spp is a species which has been found to be adapted to comparatively higher salinities (Joseph and Pillai, 1975). The bloom of the species only in the first year when higher nutrient levels coincided with higher salinities and its absence in the second year when there was higher nutrient levels but lower salinities support this.

Higher nutrient concentration favoured the bloom of other diatoms with more requirements for nutrients in preference to *Chaetoceros curvisetus,* for example *Fragilaria oceanica* and *Coscinodiscus sublineatus. Fragilaria oceanica* was reported to bloom during the monsoon season especially in the southern parts of the SW coast of India. It bloomed in June, July and August at Cochin and in June at Vizhinjam (Mathew *et al*, 1988). In the present study also, the bloom of *F. oceanica* occurred at Vizhinjam in the month of August but at lesser densities than that observed by Devassy (1974) along the coast of Mangalore where a density of 36.8×10^6 cells l^{-1} was noted. The region was brown coloured in daylight and production of foam was noted along the coastline. The bloom of the same species along the Vizhinjam coast did not produce such a colouration may be because the cell numbers were lesser.

Many reasons have been proposed for this faster response and bloom of diatoms under the high nutrient and high light conditions which occur during this period. Diatoms divide and reach bloom densities faster because of their inherently high growth rates (Smayda, 1997), accelerated nitrogen assimilation under nutrient rich conditions (Dugdale and Wilkerson, 1992), higher growth efficiency at low light (Goldman and Mc-Gilcuddy, 2003), which is important during the monsoon months when the nutrient conditions are high but light is low. Also according to Smetacek, 1995, the silica cell wall of the diatoms resist attack by small predatory flagellates or pathogens and the cracking force of the feeding structures such as copepod mandibles (Hamm *et al.,* 2003).

Phytoplankton which are capable of producing harmful blooms were recorded at both the stations. Even if most of the species were common to both the sites, their frequency of occurrence and their percentage contribution to the total phytoplankton community was different. Besides these, there were species which were unique to each site. *Prorocentrum lima, Chattonella marina* and *Gymnodinium mikimotoi* were present only at Chombala whereas *Ceratium fusus and Dinophysis miles* were unique to Vizhinjam. Of these, the major DSP producing genera *Dinophysis* formed a frequent member of the phytoplankton community at Vizhinjam, with *Dinophysis caudata* the dominant species. Considering the fact that the species has been reported to produce toxin even at very low densities between 100 to 1000 cells/ l, its constant presence in the region has to be seriously dealt with. *Trichodesmium* spp was also more frequent at Vizhinjam than at Chombala and was present at both the stations only during the pre-monsoon months, as it prefers higher temperatures as discussed in the previous chapter. The frequency of occurrence was similar at both the stations for the dinoflagellate *Prorocentrum micans* and the diatom *Psuedo- nitzschia* sp. Amnesic shellfish poisoning or Domoic acid poisoning has been proved to be caused by members of the genera *Pseudo-nitzschia* sp (Bates *et al.*, 1989). Toxin production in the same species of the genera has been found to show regional variations. Thus the same *Pseudo-nitzschia* species may be toxic in one part of the world but not in the other Bates *et al.,* 1998). *P. pungens* which was earlier thought to be as a non-toxic species has been at present indicated in some toxic events in New Zealand and from some locations in the Pacific ocean (IOC manual, 1995). *G.mikimtoi* produces both hemolytic and icthyotoxins and has caused damage in fish farms in Australia, Northern Europe, Japan and New Zealand. Regarding the period of occurrence, all toxic dinoflagellate species were present in the pre-monsoon and post-monsoon months with the frequency and densities more during the pre-monsoon period.

Even if the dominant members of the phytoplankton community of both the stations were diatoms, the flagellates increased in diversity and densities during the warmer seasons of the year. This preference of dinoflagellates to warmer seasons and to warmer parts of the ocean has been noted in many studies (Paerl, 1988; Eker and Kidey, 2000). This is because the high degree of motility allows a red tide organism to orient itself near the surface during photosynthetically active day light hours, while having the option of seeking nutrient rich waters during photoinhibitory midday or aphotic night time hours. Under thermal and salinity stratified conditions this can optimize growth and reproduction. It also represents a distinct advantage over other less motile diatoms and silicoflagellates which often coexist during the initiation of blooms (Paerl, 1988). The concentration of nutrients is also a major reason for this qualitative shift in phytoplankton from a diatom dominated community in monsoon and post-monsoon to flagellate dominated community in pre-monsoon which occurs following a progressive depletion in nutrients. According to Cushing, 1989; Azov, 1986 and Kirboe, 1993, assuming that adequate light is available for growth, high nutrient conditions in spring tend to promote larger cells, while low nutrient conditions which occurs after this major maxima of phytoplankton production select for smaller cells because of their greater efficiency relative to larger cells in uptake of nutrients under limiting conditions. It was also noted in all these studies that high turbulence can also significantly influence cell division of phytoplankton in natural conditions. Thus they noted that high nutrient concentration, a situation generally associated with high turbulence allows the development of phytoplanktonic forms like diatoms with rapid growth rates and large sizes and were lack of motility is not a disadvantage. However to persist under low nutrient conditions organisms should be motile so as to exploit resources at various levels of the water column. Thus it was noted that the diatoms blooms first utilizing the increased input of nutrients during monsoon after which smaller dinoflagellates increase in densities due to its motility and also due to its higher efficiency in uptake of nutrients present at lower levels.

The dinoflagellates which formed blooms in this study were the dinoflagellates *Noctiluca scintillans* and *D.caudata. Noctiluca scintillans* is widely distributed and forms blooms in temperate, subtropical and tropical waters. Along the west coast of India *Noctiluca* blooms were reported between August and November (Mathew *et al.,* 1988) which marked the end of upwelling along the coast. At Chombala and Vizhinjam *Noctiluca* blooms occurred in the monsoons months itself preceded by rains and diatom maxima. According to Venugopal *et al.* (1979) the high primary production along the southwest coast during monsoon owing to nutrient enrichment of waters from upwelling and estuarine discharges sets the stage for nonautotrophic forms like *Noctiluca* to bloom. Shetty *et al.* (1988) observed a cell density of 8.2×10^9 cells m^{-3}, Venugopal *et al.* (1979) observed a cell density of 3-7.7 $\times 10^5$ cells m^{-3} whereas Nayak *et al.* (2000) observed a cell density of 1.56×10^6 cells m^{-3}. High phosphate and nitrate and low nitrite was observed by Devassy and Nair (1987) during the bloom and attributed this to be the major reason for the bloom.

According to Jocelyn *et al.* (2000) *Noctiluca scintillans* is an indicator of coastal eutrophication, as in New South Wales coastal waters they observed that the frequency of occurrence has increased in recent years with increasing nutrient load. Yearly peak abundances coincided with episodic slope water intrusions (and subsequent upwelling) during spring and summer. They also observed that extensive red tides of *Noctiluca* often succeeded diatom blooms, specifically *Thalassiosira* sp, which were initiated by these intrusions. In Dapeng Bay, the South China Sea Huang and Qi (1997) observed that peak period of abundance of *Noctiluca* showed a significantly positive relationship with average water temperature, indicating that within its optimum temperature a higher temperature promotes the growth of *Noctiluca* population. Sharp declines of the population were associated with abrupt decreases in salinity due to heavy rain. In Kalpakkam coastal waters along the east coast of India an intense bloom of *N. scintillans* was observed in October 1988 showed a complete exclusion of diatoms during the peak period of the bloom. Sreekumaran *et al.* (1992) observed that along the west coast of India regular blooming of *Noctiluca* during or immediately after the onset of the monsoon occurs following an increase in phytoplankton population.

At Chombala, *Noctiluca scintillans* increased in cell densities following monsoon when there was peak phytoplankton production and bloomed when this coupled together with a break in monsoon. Hence, rich food supply is basically necessary for the species to reproduce massively, but suitable temperature, stable weather without heavy rain also seems to be important factors. The *Noctiluca* density showed a negative relationship with chlorophyll *a* concentration, indicating that this species gives a predation pressure on the phytoplankton. Complete exclusion of phytoplankton during *Noctiluca* blooms have also been observed by Subrahmanyan, 1953; Devassy and Nair, 1987 and Katti *et al.* (1988) maybe due to the heavy predation by the species. A comparatively higher value of ammonia was obtained during the bloom of the species at Thankassery and Vizhinjam. A high value of ammonia of 82 µg at/l was obtained by Nayak *et al.* (2000) during the declining stage which was attributed to be the reason for the set back to fisheries observed in the region. Similar decline in fish catch was also observed along the Indian coast during *Noctiluca* bloom very early by Bhimachar and George (1950), Prasad and Jayaraman (1954) and recently by Devassy and Nair, 1987 and Devassy, 1989). Severe fish mortality has been observed associated with a recent bloom of the species in the sea off Cochin (Naqwi *et al.,* 1998). The demersal fishes especially *Nemipterus japonicus* was the major fishes affected and the death was caused by severe oxygen depletion than due to the direct toxicity of the species. The bloom of *Noctiluca scintillans* caused a severe mortality to the pearl oysters suspended in the rafts in Thankassery which might be either due to the comparatively high ammonia content of the waters during the bloom or due to anoxia due to the higher biomass of the alga in the semi enclosed bay. A bloom of *Trichodesmium erythraeum* has been reported to cause mortality in the experimental pearl culture at Veppalodai along the east coast mainly due to asphyxiation (Chellam and Alagarswami, 1973).

Dinophysis spp formed a constant member of the phytoplankton community of Vizhinjam and reached higher cell densities once in December. The DSP toxin group includes the polyether compounds Okadaic acid, dinophysis toxin-1 and dinophysis toxin-2 and its naturally occurring derivatives. The term DSP has also been associated with shellfish poisoning due to macrocyclic polyether lactones, the pectenotoxins, proracentrolides and the fused polyether yessotoxin. The Okadaic acid/ dinophysis toxin group has been shown to be potent phophatase inhibitors and this property is linked to inflammation of the intestine and diarrhea. The mechanism of action of other compounds has not been fully established though they have been described as hepatotoxins and do not cause diarrhea. The action level set by regulatory authorities varies from country to country and in general, when the DSP toxin in shellfish exceeds 200 ng/g, closure of harvesting and marketing operations is recommended. The regular blooming of *Dinophysis* sp in summer has been observed by Lassus *et al.* (1991) Delmas *et al.* (1992) and Klopper *et al.* (2003). Lassus *et al.* (1991) concluded from their observations at the French coast that *Dinophysis* sp development occurs in relatively warm and low salinity surface waters. A stratified water body has been suggested as an essential condition also by Delmas *et al.* (1992). An increased nitrate concentration has been found to stimulate the development of high cell densities by Lassus *et al.,* 1991. Klopper *et al.* (2003) observed high concentration of ammonia in summer favours the bloom of the species.

A major species which forms regular harmful blooms along the Kerala coast is the rapidophyte *C. marina.* Blooms of *C. marina* have been reported from India (Subrahmanyan, 1954), China (Tseng *et al*, 1993), Florida (Tomas, 1998) and Japanese coastal waters (Imai and Itoh, 1987, Kotani *et al.*, 2001). Its occurrence has also been reported from Korea (Park, 1991), Brazil (Odebrecht and Abreu, 1995) and Netherlands (Vrieling *et al*, 1995). The global distribution of *C. marina* reflects the broad environmental tolerance of the species. Marshal and Hallegraeff (1999) however suggests that there are three distinct ecophenotypes with strains from Asia (Japan, Korea, China) and Australia; and Newzealand having similar temperature requirements but different light requirements and a third group inhabiting India and possibly Florida. Along the Calicut coast, the bloom of the species occurred both the years in the transition period between SW and NE monsoon indicating a well defined periodicity and annual rhythm in appearance. Along the Indian coast, bloom of *C.marina* along the Calicut coast along with associated fish mortality has been observed as early as 1917 by Hornell and by Jacob and Menon in 1948, but they could not identify the species and described it to be caused by an euglenoid. It was identified and typified as a new species *Hornellia marina* by Subrahmanyan (1954). Sexual reproduction and formation of zygote has been explained for this species by him. But the annual cycle of the algae seems to be controlled by the formation of cyst and its germination. It has been proved that there exists a benthic dormant cyst in sediments for *Chattonella spp* sometime during a certain period of their life cycle. Imai and Itoh (1986, 1987) have suggested that the overwintering dormant cells of *C marina* play an important role in initiating red tides in Seto inland sea, Japan, with temperature playing an important role in initiation of germination of cysts. In Seto inland sea where extensive study on *Chattonella* spp was carried out, it was observed that dense red tides are formed by the vegetative cells of the species in between June and August when the water temperatures rise to an adequate level of *ca* 20^0C which is higher than the normal temperatures for the region. After this the dormant cells sink to the bottom and spent a period of maturation known as spontaneous dormancy which is genetically controlled, till the next spring. So they never germinate in autumn even when the optimum temperature for germination is reached. Such a mandatory period of resting for the maturation of cysts has been also proved to be essential for the maturation of cysts in many dinoflagellate species (Dale, 1983). From spring to summer however *Chattonella* spp spent a time of post dormancy as the temperature is too low for germination. Vegetative cells appear in seawater thereafter in summer when the optimum temperature is reached. A similar lifecycle seems to be present in this study also. The vegetative cells of *C. marina* makes their appearance only in the months between late August to October and sometimes extending upto November with maximum cell numbers observed in September. At Narakkal along the Cochin coast were it bloomed for the first time, the timing was similar and followed a short transition period between southwest and northeast monsoon which is characterized by higher water temperatures than the preceding months. Such a temperature window for the germination of cysts has been pointed out for dinoflagellate cysts by Dale *et al.* (1983). Since the vegetative cells of *Chattonella* sp was observed only for this short period the species presumably spent most of their life in dormant conditions, a period of spontaneous dormancy (period of maturation) and post dormancy from late post-monsoon to late monsoon in sediments. Thus monitoring of water temperatures just before the excystment period is useful in predicting the appearance of the vegetative population in the early stage of the red tide. The optimum temperature for germination however could not be determined. The maintenance of higher temperature for the maintenance of the bloom conditions is clear from the observation that when the species bloomed at Narakkal it remained in the bloom condition more in the farm site with higher temperatures and subsided immediately with the decrease of temperature. Besides temperature, light has been also thought to be important for optimal growth of this alga. Marshal and Hallegraeff (1999) notes that of the three phenotypes, Australian strain grew well at irradiance of 400 μmol m^{-2} s^{-1} while the optimum irradiance for Japanese strains was lower of 110 μmol m^{-2} $s^{-1.}$ The optimum irradiance level for the Indian strain has not been studied but seems to be important considering the fact that species usually blooms during sunny days following a break in southwest monsoon. The intensity of bloom showed wide variation between the years at Chombala. Imai and Itoh (1985) attributes such variation in the number of vegetative cells due to failure of germination, death or secondary dormancy.

Fishes are reported to be killed by anoxia during exposure to *C. marina* red tides (Matsusato and Kobayashi, 1974; Ishimatsu *et al.*, 1990). Histological studies have shown that various red tide organisms, *C. marina*, *C. antiqua* and *Gymnodinium spp* cause severe changes in fish gills (Matsusato and Kobayashi 1974; Doi *et al.*, 1981, Endo *et al.*, 1985; Toyoshima *et al.*, 1985) probably induced through histotoxic action by these organisms. Gills of fish collected during severe *Chattonella* bloom showed damage to the primary and secondary lamellae and increased numbers of mucus cells (Tiffany, 2001). Recently neurotoxins have been isolated from these organisms (Onoue and Nozawa, 1989) and the authors reported that the neurotoxin fraction is more toxic to fishes than the hemolytic and hemoagglutinating fractions. But the presence of benthic species alone in the dead specimens indicate that in addition to the toxin the death might have been caused mainly due to some disturbance in the bottom habitat of these species. A drastic reduction in the amount of dissolved oxygen was recorded during the bloom period at the site. The heavy biomass of algae must have used up the oxygen either during respiration or during the decomposition of the heavy algal biomass. The dissolved oxygen had fallen to 0.22 mg/ l during the bloom period which was well below the normal levels. The toxins can reduce exchange of gases through the gills, resulting in osmoregulatory problems and death of the animal. Since weather and physical conditions of the sea were comparatively stable at the time of the bloom, it is possible that the mortalities could be attributed to low lethal oxygen concentrations associated with the dinoflagellate bloom and its decay. The emergence of *Mactra* sp, *Emerita* sp also suggest oxygen depletion in benthic strata. Kim *et al.* (2003) based on experiments on the short necked clam *Ruditapes philippinarum* suggested that reactive oxygen species (ROS)-mediated gill tissue damage is one of the causative factor responsible for the harmful effect of *C. marina* on shellfish. The present study noted a heavy mortality of demersal fishes during the bloom of the species at Chombala. The toxin analysis at CIFT showed the presence of a lipid soluble toxin which caused mortality in mice. Both the toxin and low dissolved oxygen level must have caused the fish mortality. *Chattonella marina* which has been previously reported along the Calicut coast in the past, formed a heavy bloom in September 2003 at Narrakkal for the first time. Though the bloom subsided very soon in the sea it remained in the farm for almost three weeks maybe because of the higher water temperatures in the farm area when compared to the adjacent sea and also because of lower flushing rates. The bloom resulted in heavy mortality of shrimps in the region. Toxin analysis at CIFT showed the presence of a toxin similar to that from Chombala.

Thus the phytoplankton blooms in the study sites clearly follows a pattern. One pattern is the restricted seasonal occurrence as exemplified by marine diatoms that dominate spring blooms. A second pattern is the non seasonal population growth of dinoflagellates in response to short term events such as sunny calm weather that establishes thin upper layer within which motile species accumulate. *Noctiluca* blooms seems to always follow diatom maxima and stable weather *Chattonella marina* illustrates a different seasonal pattern similar to that of dinoflagellates but the bloom is triggered by the excystment of cysts which seems to be genetically controlled and triggered by an increase in water temperature.

CHAPTER III

3. EFFECT OF *Chattonella marina* BLOOM ON THE COASTAL FISHERY RESOURCES ALONG THE CALICUT COAST

3.1. INTRODUCTION

Bloom of toxic or harmful microalgae pose a serious threat to human health, coastal activities and fishery resources through out the world. In addition to the toxicological effects on humans, several kinds of microalgae may directly affect wild and cultivated fish or marine invertebrates that are valuable seafood and cause significant economic impacts through fish kills, farm closures, avoidance of shellfish by consumers etc. (Shumway, 1990; Anderson *et al.*,1989). Commercial fishery impacts from HAB's, including wild harvest and aquaculture losses due to NSP, PSP, ASP, Ciguatera and brown tides has been estimated to be around US $18 million in the United States (Anderson *et al.*, 2000) and around 1.2 m US $ in China (Yan *et al.*, 2003).

Fish kills are mainly due to *Gymnodinium nagasakiense* in the North Sea region and due to *Heterosigma akashiwo* in British Columbia, Chile and New Zealand. *Gymnodinium breve* has also been implicated in many fish kills (IOC report, 1991). A massive fish kill by *C. polylepis* in 1988 in the North Sea was reported to cause death of 900 tonnes of fishes such as cod, salmon and trout (Moestrup, 1994). Blooms of *Noctiluca,* a heterotrophic dinoflagellate has resulted in fish and faunal kills in their regions of occurrence, as it is capable of build up of extracellular ammonia which rapidly kills the species which are unable to escape the bloom areas (Paerl, 1988). Predation by *Noctiluca scintillans* on the eggs of *Engraulis japonica* (Enomoto, 1956) has also been reported. *Pfesteria piscida*, a fish killing dinoflagellate is a recently reported harmful species which has been linked with fish kills in the mid Atlantic region. (Burkholder *et al.*, 1992; Burkholder and Glasgow, 1995). Besides producing chemical substances which are directly toxic, some micro algae physically damage the fish gills which result in osmoregulatory problems and death. Gelationous secretion during the bloom of the diatom *Coscinodiscus waleisii* in North Sea negatively affected the commercial fishery of the region (Boalch, 1984). The spine bearing algae *Chaetoceros convolutus* and *C. concavicornis* can cause mechanical clogging or lesion of gills (Bell, 1961; Yang and Albright, 1992; Rensel, 1993). *Chattonella antiqua* and *Chattonella marina* are the major cause of fish mortality in aquaculture farms in Japan. The rapidophytes has been identified to produce neurotoxic, haemolytic and haemoagglutinating compounds as well as superoxide and hydroxyl radicals which cause severe damage to fish gills leading to osmoregulatory problems and death (Endo *et al*, 1992; Tanaka *et al.*, 1994; Ahmed, 1995).

Large-scale mortality of marine fishes has also been reported to occur as a result of the transfer of algal toxins through the food web. The toxic dinoflagellate *Gonyaulax excavata* has been reported to cause mortality in Atlantic herring, sand lance and menhaden as a result of PSP toxin transferred through the herbivorous zooplankton which grazed upon it (Adams, 1968; White, 1981). Juvenile and larval stages of fish have been found to be more vulnerable to algal toxins. According to Gosselin (1989) the emergence of fish larvae and early post larvae at a time when planktonic food web is contaminated by algal toxins could lead to a significant reduction of early survival and threaten recruitment to local stocks. Vulnerability of fish larvae to toxic dinoflagellates has been discussed in detail by Rodineau (1991).

Noctiluca, Trichodesmium and *Chattonella marina* are the species with regular bloom occurrence along the Indian coast (Subrahmanyan, 1954; Karunasagar and Karunasagar, 1990). Sporadic blooms of other toxic algae has also been reported. A normal diatom dominated bloom is usually considered favourable for the fishery production of the region. An increased phytoplankton density has been linked to an abundance of oil sardine and mackerels by Subrahmanyan (1959). The abundance of the diatom *Fragilaria oceanica* is considered as an indicator for the abundance of oil sardine. But harmful blooms are unfavourable to the fishery of the region. Fishes tend to avoid such areas of bloom either due to the heavy biomass or due to the production of toxic substances which are harmful to it. *C.marina* first described by Subrahmanyan (1954) along the Calicut coast has been associated with fish and faunal mortality and fish avoidance along the Indian coast since the early period of the last century (Hornell, 1917; Chacko, 1942; Jacob and Menon, 1948). A set back to fisheries operations in Malabar and Kanara coast due to the bloom of *Noctiluca* has been reported by Bhimachar and George (1950). A decrease in landings of oil sardine and mackerel was noted by Prabhu *et al.* (1971), during the bloom of *Trichodesmium erythraeum* along the Mangalore coast. A sudden fall in tuna catches was noticed during the bloom of the same species around Minicoy island (Naghabushanam, 1967). Red tide and its deleterious effects on the fishery of the Goa coast was studied by Devassy (1989).

It is clearly evident from all these works in the Indian region that the fishes avoid areas where these harmful algae bloom either due to toxicity or due to some irritant property of the chemicals secreted by the algae. The nearshore regions of Calicut coast in north Kerala, is a zone where harmful algae bloom and remain in the bloom state for a consistently longer period than in other regions. The change in the ecosystem is bound to affect the fishery resources of the region as well, which will be reflected in the catches landed in the region. To assess the impact of the blooms on these resources, the variation in total landings and the composition of catch during the period from October 2001 to December 2003 was analysed.

With an annual marine fishery potential of 3.93 million tones and a current annual production of 2.6 million tones, India occupies an important position among the fishing nations bordering the Indian Ocean. Characteristic of tropical seas, the Indian fishery is multispecies comprising over 200 commercially important species of finishes and shellfishes and multigear with fishing practices varying between different regions depending on the nature of fishing grounds and the distribution of the fisheries resources (Srinath *et al.,* 2005). Pelagic and demersal fishes like mackerel, sardines, white baits, ribbon fish, carangids, seer fishes, tunas, croakers, threadfin breams, silver bellies, catfish, lizard fish, flat fish, snappers, breams, groupers, bull's eye, goat fish, crustaceans like prawns, crabs, lobsters and stomatopods and molluscs like gastropods, bivalves and cephalopods are the major resources exploited.

Calicut is one of the important marine fish landing centers of Kerala. The important gears used in and around Calicut coast are trawl net, ring seine, gill net, boat seine and hook and line. The mechanized trawlers include both single and multiday operated units. In addition to this, trawl nets are also operated from crafts fitted with outboard engine and includes, mini trawl operated by single craft and minipair trawl operated by two crafts. The gill nets are of different types and include 'Chooda vala', 'Ayila chala vala' and 'Ozukku vala' depending on their mesh size. Hooks and lines are used as long lines, hand lines or troll lines. 'Long lines' are mainly used for shark fishing. The crafts include wooden boats with an OAL between 9 to 17 m from which trawl nets are operated, fibreglass and fiberglass coated marine plywood boats with OAL between 14 and 16m from which ring seines are operated. Besides these, gears are also operated from plank built boats with an OAL of 8-9m (Sivadas, 1993).

The fishery of the region consist of the pelagic fishes such as sardine, mackerel, the white bait *Stolephorus* sp, seer fish *Scomberomorus* sp, tunas such as *Euthynnus affinis, Auxis thazard, Thunnus tonggol* and *Sarda orientalis,* of which only *Euthynnus* sp formed an year round fishery, and the pomfrets *Parastromateus niger* and *Pampus argenteus.* The demersal groups include the sole *Cynoglossus* sp, the catfish *Arius* sp, sharks such as *Carcharhinus melanopterus, Scoliodon laticaudus* and *Rhizoprionodon acutus*, sciaenids and the prawns *Parapenaeopsis stylifera, Metapenaeus dobsoni, M.affinis, M.monoceros, Penaeus indicus* and *P.monodon* (Sivadas, 1993).

To assess the impact on nearshore fisheries, especially in the region where the bloom prevailed, the landings of the main gears which operated in the region namely mechanized single day operated trawl, mechanized multiday trawl, outboard trawl, gillnet ring seine and drift net with outboard engine, non mechanized gill net were monitored. Apart from this, the impact of bloom on the marine fishery resources was also measured by the taxonomic diversity indices.

3.2. MATERIALS AND METHODS

The harmful alga *Chattonella marina* bloomed in the coastal waters of Calicut in September 2002 and 2003 during the study period (October 2001 to September 2003), the details of which is discussed in Chapter 2. The impact of these two blooms on the coastal resources was assessed by analysing the effect on the coastal fishery and from the variations in the commercial fish community structure. Effect on the fishery was studied by analysing the variation in the marine fishery landings of Calicut zone, with monthly landings and catch per unit effort of a specific gear as index of abundance of the resource, while the effect on community structure was studied from the variation in the taxonomic distinctness. The detailed methodology is given below.

3.2.1. EFFECT ON FISHERY

For assessing the effect of *Chattonella marina* bloom, the fishery data collected by the CMFRI for the K-8 B zone of Calicut region was used, since the areas with regular bloom occurrences come under this zone. The macro-level changes observed in the preliminary database, were used to trace the micro-level species specific variations. The following inputs were used to identify the main marine commercial fishery resources which are affected by the blooming of *Chattonella marina.*

A. Fishery data: The marine fish landing data of Calicut region collected by the Fisheries Resource and Assessment Division (FRAD) of Central Marine Fisheries Research Institute following the Stratified multistage random sampling method (Srinath *et al.*, 2005) was used as the primary data base. The total landings for a region is estimated by computing the catch and effort of the gears operating from different landing sites within this zone (CMFRI, 1972; 1982).

B. Fishery data collection sites: The catch from the fishing crafts operating in the K-8 B zone of Calicut region, under which comes the regular areas of bloom, are landed in the two major harbours namely Chombala and Puthiyappa and in the 3 major landing centers and 11 minor landing centers (Fig. 3.1). The landing from all these sites is used for estimating the monthly landing of K-8 B zone of Calicut region.

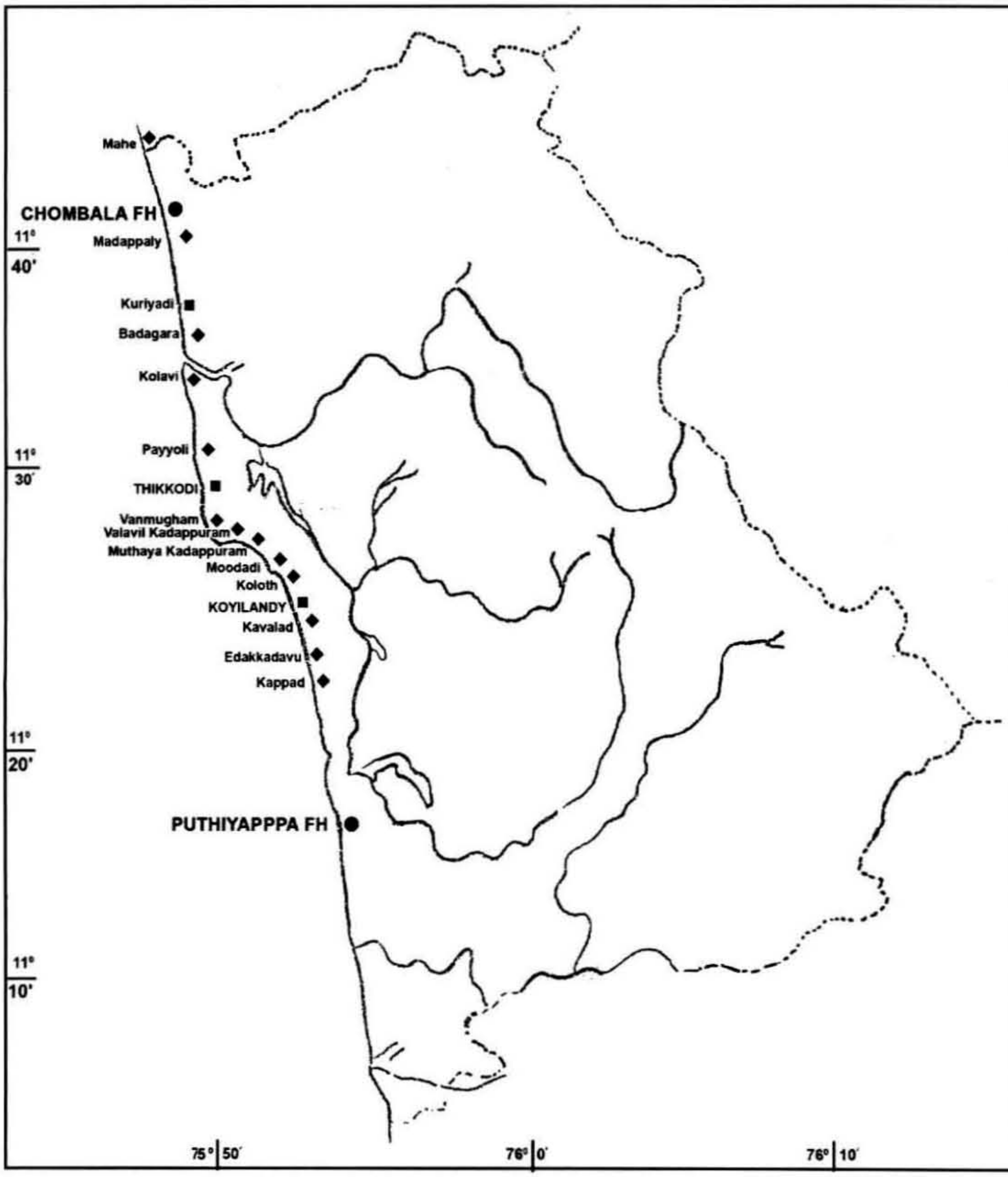
C. Fishing craft and gear: 6 mechanized gears viz. trawl net (single and multiday), gill net, hook and line, drift net, boat seine, ring seine and 3 non mechanized gears viz. gill net, boat seine and hook and line are the major gears operated from these landing centres. The landing from all these gears which generally operate within an average maximum distance of 55 km from the shore were considered for estimating the landing of this zone. For the present study, the catch of all the gears was pooled except that of multiday trawl net since its area of operation is far beyond the bloom area.

D. Period of Study: For assessing the impact of the bloom, the variation in magnitude of total monthly landings during the period between October 2002 and December 2003 was used. The bloom in September 2002 when the alga bloomed at a density of 28×10^{7} cells l^{-1} was taken as Bloom I and the bloom in September 2003 when it reached a bloom density of 17×10^{4} cells l^{-1} was taken as Bloom II. Rest of the period when this particular alga was not present was considered as non-bloom months.

E. Impact on resources: The catch estimates pertaining to 66 genera of finfishes (33 pelagic and 33 demersal), 13 crustaceans and 4 cephalopods were collected by the FRA Division for the region. The crustaceans were composed of mantis shrimps, crabs and lobsters while squids, cuttlefishes and octopuses formed the molluscan component. Impact grading of species was based on the presence/ absence of the species and the variation in the magnitude of the monthly landing. Accordingly, the resources were graded into four categories.

1) Species present only during the bloom.
2) Species present in the catch all throughout the year, except during the bloom period.
3) Species which were present in the catch all throughout the year including the bloom period, but whose magnitude of landings decreased during the bloom period over that of the non-bloom period.
4) Species which were present in the catch all throughout the year including the bloom period, but whose magnitude of landings increased during the bloom period over that of the non-bloom period.

Fig. 3.1. Map of landing centers in K-8 B zone, Calicut



- ● Fishing harbours
- ■ Major landing centers
- ◆ Minor landing centers

STEP-WISE PROCEDURE FOLLOWED FOR FISHERY DATA ANALYSIS

1. The landings for each gear for each landing center was estimated and this was pooled to estimate the monthly landing by a particular gear for the zone.
2. The data from all the gears for each month was pooled to obtain the total monthly landing for the zone.
3. The total and gearwise monthly catch was estimated for each species and grouped into pelagic and demersal finfishes, crustaceans and molluscs.
4. The magnitude of variation of catch for each group was critically analyzed and micro-level tracing within each group was done. Only those resources whose landings showed variation during the bloom period were selected for further analysis.
5. To analyse the impact for specific resources which were found to be affected by the bloom, the fishery at Chombala was studied in particular and micro-level analysis was done with reference to catch from gears operated from this region.
6. Microlevel analysis of the resources which were found to be affected as indicated by the monthly landing was done by critically analyzing the variation in catch per unit per day between the bloom and the non-bloom period. Here, the catch of a particular species in a specific gear was considered. Data was not pooled to avoid the error due to variation in efficiency of the gear. The species which were subjected to this analysis were *Cynoglossus* sp, *Johnius* sp, *Thryssa* spp, *Parapenaeopsis stylifera, Metapenaeus dobsoni, Penaeus indicus* and *Leiognathus* in outboard trawl net, *Euthynnus* and *Scomberomorus commerson* in ouboard drift net and *Sardinella longiceps* in outboard ring seine.
7. To find the effect of bloom on a specific marine resource, the catch per unit effort per day (CPUE) for these resources during the immediate pre-bloom and post-bloom period was compared with that of bloom period. This microlevel analysis was thus restricted to 6 months. May, July (excluding the trawl ban period) and August were considered as pre-bloom period since in June and July (partly) the fishery was low due to the unfavourable weather conditions. Moreover the trawl ban enforced by the government of Kerala was also in vogue during this period. October and November were considered as post-bloom period when *Chattonella marina* was not present at the site and also when there was no bloom of any other species.
8. For assessing the significance of variation of CPUE of species subjected to microlevel analysis, one-way ANOVA was done using the SPSS 7.5 software and for those species

which showed significant variation between these study periods, post hoc Duncans test was done.

3.2.2. EFFECT ON COMMUNITY STRUCTURE

TAXONOMIC DIVERSITY INDICES

Species richness is heavily dependent on sampling effort, which is highly variable in this case and since only the weight of the fishes landed were obtained and not the numbers, the taxonomic diversity index, viz. average taxonomic distinctness (Clarke and Warwick, 1998) was calculated.

Taxonomic diversity indices are a type of diversity indices which are based on relatedness of the species within the sample. These indices are based on the assumption that a sample containing species belonging to different taxonomic levels are more diverse than samples containing species from the same taxonomic levels. This is usually defined from a Linnaean classification and requires an aggregation file in addition to the data worksheet. The aggregation file is used as a look up table which gives the taxonomic relationship and the distance apart of any two species in the sample. The taxonomic tree constructed consisted of 7 levels starting from the genus level and extending through family, suborder, order, class upto the level of phylum. All branch lengths were given equal weights.

a. AVERAGE TAXONOMIC DISTINCTNESS (Av TD)

Average taxonomic distinctness is defined as the average path length between any two randomly chosen species present in the sample. This measure uses the presence/absence data of the species in the sample and is calculated as given by Clarke and Warwick (1998) as

$$\Delta^{+} \quad = \quad [\sum\sum_{i<j} \omega_{ij}] / [S(S-1)/2],$$

where S is the observed number of species in the sample, and the double summation ranges over all pairs i and j of these species($i<j$).

b. EXPECTED DISTINCTNESS TESTS AND FUNNEL PLOTS

When the data are reduced simply to presence/ absence, not only distinctness Δ^{+} can be compared across samples of different size but a significance test can also be carried out which tests for departure of Δ_m^{+}, the distinctness measure for any sample of m species, from the overall value Δ^{+} for a master species list for that region. The test is based on the assumption that the average taxonomic distinctness of a randomly selected sublist does not differ in mean value from the average taxonomic distinctness of a master list. This tests for departure Δ_m^+, the distinctness measure of any sample of *m* species from a global species list for that region. The test is based on the theoretical mean and variance of Δ_m^+ values obtained by random sampling of *m* species from the total list of *s* species (Clarke and Warwick, 1998). Although the theoretical mean remains constant, the variance naturally increased as *m* decreases and so the approximate 95% confidence interval takes the form of a funnel. The values of Δ^+ for any particular set of samples can then be related to this confidence funnel to find the extent to which their taxonomic distinctness falls significantly below or above the expected distinctness. Assuming a null hypothesis that each sample is a random selection from the total species list, all values of Δ^+ should fall within the confidence funnel.

A whole taxonomy list prepared from all the fishes, crustaceans and molluscs present in the landings of the region during the study period which was classified based on Linnaean system of classification was used for the construction of the master species list. The fishes were classified according to Munro (1955), crustaceans according to Holthius (1980, 1990) and cephalopods based on Roper *et al.* (1984).

3.3. RESULTS

3.3.1. EFFECT ON THE FISHERY OF CALICUT ZONE

TOTAL LANDINGS

A. VARIATION IN TOTAL LANDINGS

The total landings in the Calicut region, from all the gears excluding multiday trawl net showed a reduction during Bloom I (Fig. 3.2). The total landings decreased from 5963 t in August 2002 to 4240 t in September 2002 when there was a massive bloom of the harmful alga *Chattonella marina* and decreased further to 4173 t in October. The low fish catch was mainly due to a reduction in demersal landings from 1532 t in August 02 to 67 t in September 02, which further decreased to 45 t in October. The landings improved by the next month. The landings of crustaceans decreased steeply from 100 t in July to 2.2 t in August 02 and 1.3 t in the bloom month and increased to 2.1 t in October and 73.7 t in November 02. Cephalopods which were absent in the landings in the pre and post-bloom periods recorded a heavy landing of 336 t which was composed entirely of *Sepia* sp. The pelagic catch however showed an increase from 848 t in July to 4075 t in August and 4171 t in September.

There was a variation in catch during Bloom II also. The landings reduced from 3813 t in July 03 to 2844 t in August, which increased to 3002 t in September. In October 03 there was however a sharp increase to 21,806 t due to a bumper catch of oil sardine. The demersal landings which increased from 454 t in July to a high value of 734 t in August 03 decreased to 45 t in September, which later increased to 241 t in October. The landings of crustaceans were very low which decreased from 44 t in July to 26 t in August which further decreased to 0.7 t in the bloom month and 0.1t in the post-bloom month of October 03.

B. VARIATIONS IN FISHERY RESOURCES

The major species which were affected by the bloom, and their variation in the fishery landings is represented in Table.3.1.

i). Species which appeared in the fishery only during the bloom

Appearance of some fish species were noted only during the bloom month, when *C.marina* was present in high cell densities in the region and the months just preceding and succeeding the bloom. This included the pelagic fishes *Albula vulpes, Auxis* sp, *Istiophorus* sp, *Trichiurus* sp and the demersal fishes *Arius* sp, *Pristipomoides* sp, *Scoliodon* sp, *Echeneis* sp and the ray *Himantura* sp. Among these, *Auxis* sp, *Istiophorus* sp, *Himantura* sp, occurred again in the fishery during the bloom of *C. marina* in Bloom II also.

ii). Species which were absent in the fishery only during the bloom period

The clupeid *Stolephorus* sp and the crustaceans *Portunus pelagicus, Portunus sanguinolentus* and *Parapenaeopsis stylifera* which were present throughout in the landings from the region were absent during Bloom I. During Bloom II, the fishes *Stolephorus* sp, *Leiognathus* sp and the crustaceans *Metapenaeus dobsoni, Parapenaeopsis stylifera, Portunus sanguinolentus* were absent in the landings from the region.

iii). Species whose catch decreased during the bloom period

The groups whose landings showed a general decreasing trend were mainly the carangids and the crustaceans. The landings of *Caranx* sp, *Thryssa* sp, *Johnius* sp, *Megalaspis cordyla*, *Leiognathus* sp and the shrimp *Penaeus indicus.* Besides these, the benthic fish *Cynoglossus* sp, also showed a reduction in total landings during the bloom period. During bloom II a reduction in landings of almost the same species were observed. The landings of the carangids, *Johnius* sp, *Megalaspis cordyla* and *Thryssa* sp decreased during the bloom. *Caranx* sp was less in the pre and post-bloom period but was slightly higher in the bloom month of September. The landings of *Penaeus indicus* and *Cynoglossus* also decreased during the bloom.

Table.3.1. Pictorial representation of the variations in fishery community of the region during the bloom in September 2002 and September 2003 in comparison with the immediate pre and post-bloom period.

	O	N	D	J	F	M	A	M	J	A	S2	O	N	D	J	F	M	A	M	J	J	A	S3	O	N	D
Albula vulpes																										
Auxis sp																										
Caranx spp																										
Euthynnus sp																										
Istiophorus sp																										
M.cordyla																										
Scomberomorus sp																										
Sardine spp																										
Sphyraena spp																										
Stolephorus sp																										
Thryssa spp																										
Trichiurus sp																										
Arius sp																										
Carcharhinus sp																										
Cynoglossus spp																										
Echeneis sp																										
Epinephelus spp																										
Himantura sp																										
Johnius spp																										
Leiognathus spp																										
Muraenesox sp																										
Priacanthus sp																										
Pristipomoides sp																										
Saurida sp																										
Scoliodon spp																										
C.luciferase																										
M.dobsoni																										
P.stylifera																										
P.pelagicus																										
P.sanguinolentus																										
Sepia spp																										

Species present only during the bloom

Species absent only during the bloom

Increased during the bloom (Intensity of colour increasing with the increase in abundance

Decreased during the bloom (Intensity of colour increasing with the decrease in abundance

S2 and S3-Bloom I and Bloom II

iv). Resources whose catch increased during the bloom period

The resources which showed increased catch during the bloom, were *Sphyraena* sp, *Saurida* sp, *Priacanthus* sp, *Euthynnus* sp and *Epinephelus* sp and the cephalopod *Sepia* sp. The catch of *Euthynnus* which increased during the bloom in September, showed an increase in the landings in the second bloom also.

GEAR WISE LANDINGS

1. OUTBOARD TRAWL NET (OBTN)

A.VARIATION IN TOTAL LANDINGS

The OBTN (hand trawl) operates very close to the shore at a distance ranging between 1 to 15 km and at a depth between 3 and 24 m. The total landings in the pre-bloom month of August 2002 was very low of 4.1 t when compared to 231 t in July 2002. It increased slightly to 9.7 t in September followed by a decrease to 3.4 t in October and increased thereafter. In the following year the landings increased from 77 t in July 2003 to 289.6 t in the pre-bloom month of August 2003 which decreased to 5.3 t during the bloom month with a further reduction to 1.9 t in the post-bloom month which increased thereafter. The landing data of the major groups landed in the gear is represented graphically in Fig .3.3.

B. VARIATION IN RESOURCES

In Bloom I *Arius* sp was the major species landed and this resource was observed in OBTN only in the bloom period in both the years. *Arius* was present in the landings in August (0.38 t) and in September 2002 (5.02 t). It again occurred in the fishery during Bloom II with a landing of 4.9 t. The catch of *Thryssa* spp and *Johnius* spp showed a decreasing trend during Bloom I and II. *Thryssa* spp was absent in the post-bloom month of October in both the years. The landing of *Leiognathus* spp and *Cynoglossus* spp also decreased and this fish was absent in October in Bloom I and II. The catch of *Metapenaeus dobsoni* and *Penaeus indicus* showed a decrease with the bloom and was absent in the post-bloom months in both the years.

C. ANOVA and DUNCANS TEST

The variation in catch rate of *Cynoglossus* spp, *Johnius* spp, *Thryssa* spp, *P.stylifera, M.dobsoni, P.indicus and Leiognathus* spp in Outboard trawl net operated in the coastal waters of Chombala were analysed. The average catch during the months of analysis for Bloom I along with the results of the ANOVA and Duncans post-hoc tests are given in Table 3.2. Of these, the variation in catch rate between the bloom and the non-bloom period was significant ($P<0.05$) for *Cynoglossus* spp, *Johnius* spp, *Thryssa* spp *and P.stylifera.* Catch of carangids *Johnius* spp *and Thryssa* spp showed significant variation ($P<0.05$) between the bloom and the non-bloom period. The average catch per unit of *Johnius* spp showed a decrease in September (0.33 kg) when the harmful microalgae *C.marina* bloomed. The average catch per unit were similar in the pre-bloom months of May (4.48 kg), July (4.35 kg), August (2.95 kg) and the post-bloom months of October (4.47 kg) and November (4.67 kg). In the case of *Thryssa* spp, the catch per unit was lower in the bloom month of September (1.17 kg) and in the preceding months July (3.9 kg) and August (1.38 kg) also. The average catch per unit of *Thryssa* spp was however higher and similar in the pre-bloom month of May (6.17 kg) and the post-bloom months of October (7.07 kg) and November (6.33 kg).

The result of analysis of variance showed that the variation in landing was highly significant for the benthic fish *Cynoglossus* spp ($P<0.05$). The average catch per unit was low from July to September and increased immediately in October following the bloom. It was higher and similar in May and November than the bloom months. The catch rate of the shrimp *Parapenaeopsis stylifera* also showed significant differences ($P<0.05$) between the bloom and the non-bloom months. The average catch per unit effort showed a decreasing pattern with the bloom with the highest in pre bloom month of May and decreasing to nil landings in the bloom period from August to September and thereafter increasing again. Beside the above species, the CPUE of *M.dobsoni, Penaeus indicus* and *Leiognathus* showed a variation during the bloom period. The differences were however not significant ($P>0.05$).

During Bloom II catch per unit effort showed significant variation for *Cynoglossus* spp ($P<0.05$) while it was not significant for *Johnius* spp and *P.indicus*. The average catch during the months of analysis for Bloom II along with the results of the ANOVA and DMRTare given in Table. 3.3.

2. MECHANISED TRAWL NET (MTN)

A.VARIATION IN TOTAL LANDINGS

Mechanized trawl is operated in the region at a distance which ranged between 2 and 35 m from the shoreline and at a depth between 4 and 35 km. The MTN operations were cancelled completely in Bloom I due to the prolonged bloom in the region. When the fishery resumed in October, the total catch was 6 t for the month, which was very low when compared to 1780 t in August 2002 (pre-bloom month). However the fishery steadily increased thereafter. The catch of the major groups landed in the gear is represented graphically in Fig. 3.4.

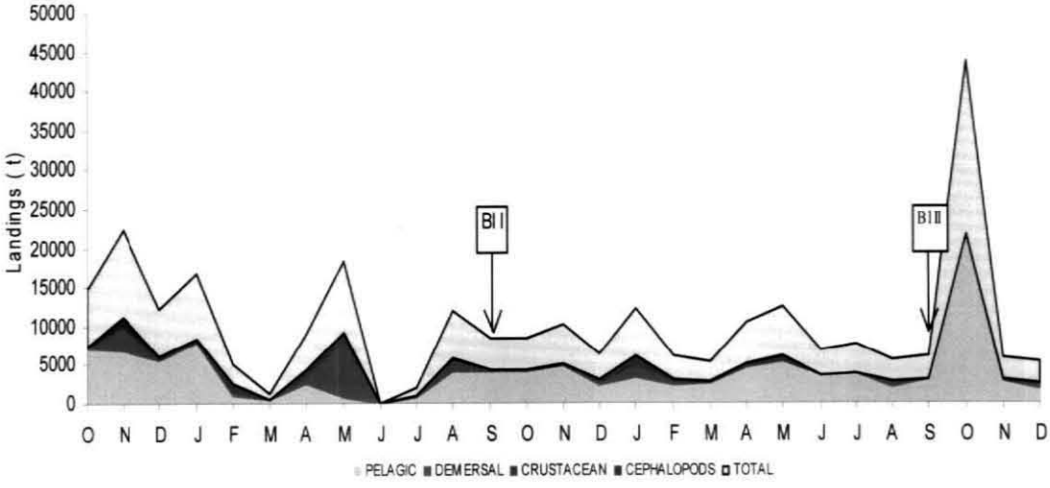


Fig. 3.2 Groupwise total landings by all gears at Calicut region from Oct 01 to Dec 2003

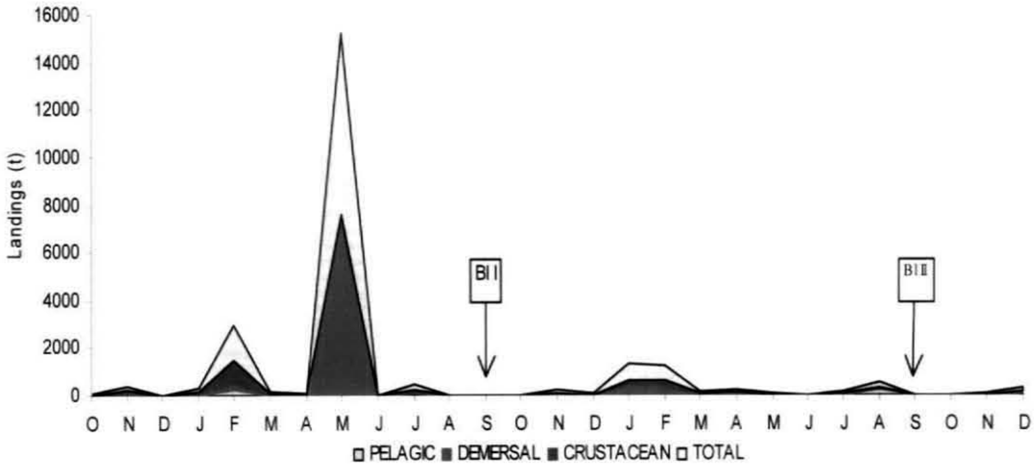


Fig. 3.3 Groupwise landings of outboard trawl net at Calicut region from Oct 01 to Dec 2003

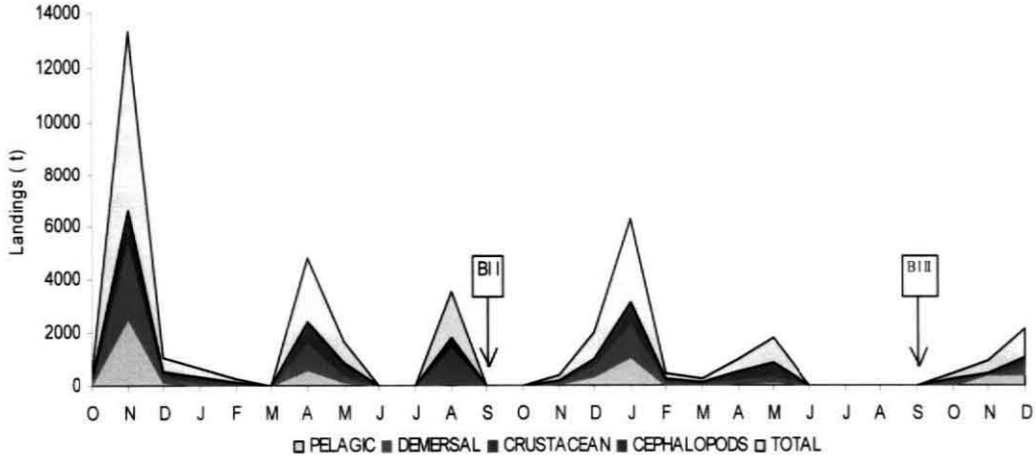


Fig. 3.4 Groupwise landings of mechanised trawl net at Calicut region from Oct 01 to Dec 2003

Table. 3.2. Average catch per unit effort (kg) of major fish species which showed variations in the landings of Outboard trawl net during the bloom period in September 02 and results of ANOVA. *

Species	F value	P	Average catch per unit (kg)					
			Pre-bloom	Pre-bloom	Bloom	Bloom	Post- bloom	Post bloom
			May	July	August	September	October	Nov
Cynoglossus sp	22.58	0.000	20.9[a]	9.4[b]	0[b]	0.7[b]	52.5[c]	38.2[c]
Johnius sp	7.991	0.001	4.48[b]	4.35[b]	2.95[b]	0.33[a]	4.47[b]	4.67[b]
Thryssa sp	5.267	0.009	6.17[a]	3.9[b]	1.38[b]	1.17[b]	7.07[a]	6.33[a]
Parapenaeopsis stylifera	7.244	0.029	6.37[b]	2.8[a]	0[a]	0.1[a]	3.1[ab]	5.49[ab]
Metapenaeus dobsoni	0.562	0.693	1.17[a]	1.5[a]	0.97[a]	2.07[a]	1.18[a]	1.369[a]
Penaeus indicus	1.369	0.298	[a]	1.57[a]	0.783[a]	0.15[a]	0.083[a]	0.143[a]
Leiognathus sp	1.081	0.404	[a]	13.45[a]	0.42[a]	14.37[a]	6.3[a]	[a]

Table. 3.3. Average catch per unit effort (kg) of major fish species which showed variations in the landings of Outboard trawl net during the bloom period in September 02 and results of ANOVA. *

Species	F value	P	Average catch per unit (kg)				
			Prebloom	Prebloom		Bloom	Post bloom
			April	May	June, July	Aug, Sept	October, Nov, Dec
Cynoglossus sp	21.52	0.000	21[a]	3.4[b]	3.2[b]	4[b]	63.8[c]
Johnius sp	3.998	0.031	0[a]	1.3[ab]	6[c]	3.9[bc]	2.3[abc]
P.indicus	1.219	0.357	0.058[a]	2.37[a]	0.77[a]	1.16[a]	[a]

*Results of DMRT are shown as superscripts
Nonidentical superscripts (row wise) indicate months with significant differences ($P<0.05$).

B. VARIATION IN RESOURCES

The total landing in the pre-bloom month of August 02 was mainly due to the high demersal component of 1375 t composed of *Saurida* sp, *Priacanthus* sp and *Epinephelus* spp and cephalopod landing of 335 t. *Priacanthus* sp and *Saurida* sp were caught mainly from this gear during this period, with 373.4 t and 772.4 t respectively. The landing of pelagic fishes were low during the pre-bloom month mainly due to a decrease in fishes of the lowest trophic level especially sardine. Landing of sardine was nil from August to October 2002 which increased slightly to 36 t in November 2002 and increased steadily thereafter. The pelagic landing in August 2002 was contributed mainly by the predatory fish species *Sphyraena* with a landing of 56 t.

3. OUTBOARD DRIFT NETS (OBDN)

A.VARIATION IN TOTAL LANDINGS

The OBDN is operated further away from the shore which ranges between a distance of 15 and 55 km and at a depth between 35 and 70 m. The OBDN landings was high in the bloom period between August to October 2002 in Bloom I and again in September 03 during Bloom II. The highest landing during the study period was in August 2002 with 564 t. It decreased to 219 t in the bloom month of September and decreased steadily thereafter. In Bloom II also there was again an increased landing of 237 t in September, which decreased thereafter to 9.3 t in October 2003. The landing data of the major groups landed in the gear is represented graphically in Fig. 3.5.

B. VARIATION IN RESOURCES

The increased landings in both the years during the period between August to October was mainly due to increased landing of tunas from the region. In September 03 however the increased landing was due to the catch of 102.7 t of *Trichiurus* sp, 33.7 t of *Euthynnus* sp and 31.57 t of *Scomberoides* sp. The increased catch of tunas, sharks and catfishes to the total landings of the region was mainly due to the increased landings of these fishes in this gear. The total catch of tunas was 424.3, 167.6 and 28.2 t respectively in August, September and October 2002. The increased demersal landings in the period from August to October 2002 was also due to fishes at the higher trophic level mainly shark and catfishes. Among the sharks, the landing of *Carcharhinus* sp increased to a high value of 26.44 t in the pre-bloom month of August 2002 which decreased to 1.23 t and 0.124 t in the succeeding months whereas *Scoliodon* sp increased steadily from 0 to 0.28, 4.8 and 4.96 t in September and October 2002 and to nil landings in the following month. The catfish *Arius* sp was landed only during the period from July to October 2002 with landings of 0.24, 21.7,12.6 and 13.6 t respectively.

Sardinella sp which is usually not caught in OBDN along the Calicut coast was obtained during the period from August to October 2002, with peak landing of 0.9 t during the bloom in September 2002 compared to 0.024 t in the pre and 0.015 t in the post-bloom month. *Rastrelliger* sp was present from July to October 02 with the highest landing of 12 t in the pre-bloom month of August 2002 and 10.8 t in October and 1.49 t in September 2002. Other finfish species which

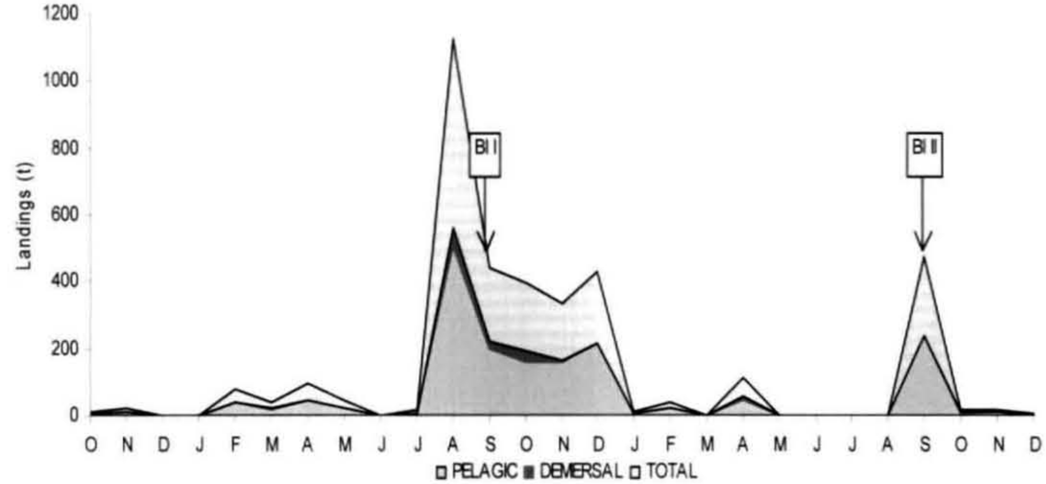


Fig. 3.5 Groupwise landings of outboard drift net at Calicut region from Oct 01 to Dec 2003

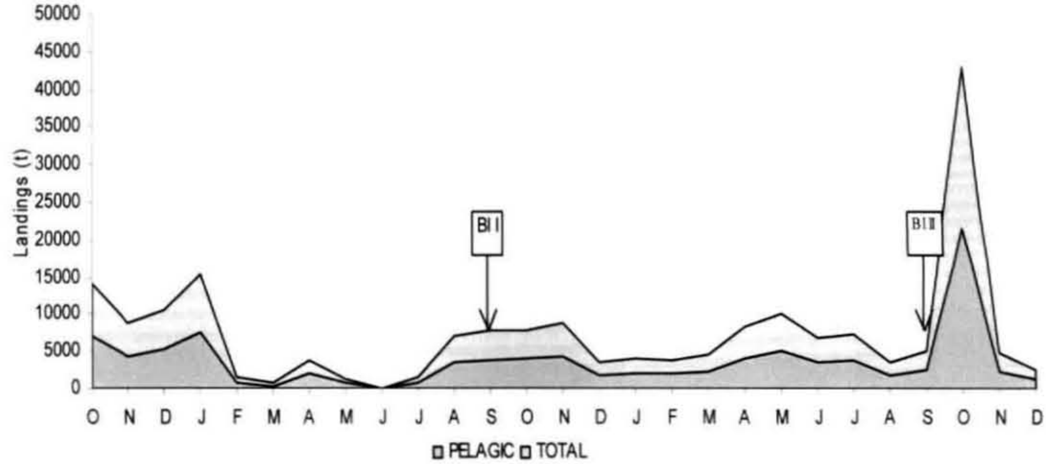


Fig. 3.6 Groupwise landings of outboard ring seine at Calicut region from Oct 01 to Dec 2003

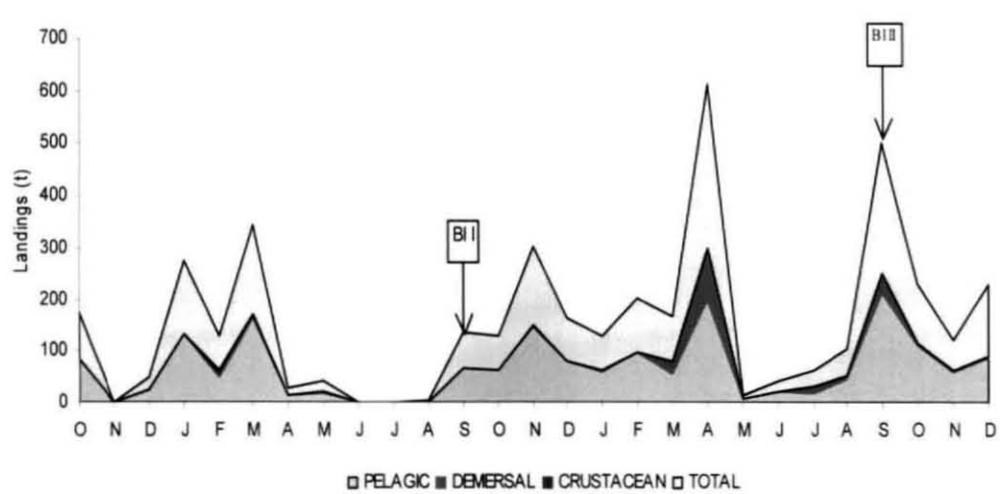


Fig. 3.7 Groupwise landings of outboard gill net at Calicut region from Oct 01 to Dec 2003

occurred in the landings only during the bloom period included the predatory fishes such as *Trichiurus* sp and *Chirocentrus dorab.* A high catch of 102.8 t of *Trichiurus* sp was recorded in September 2003 during the second recorded bloom of *C.marina*. It was also present during the bloom in September 2002. *C.dorab* was present from September to December 2002 and again during September and October 03.

The bony fish *Albula vulpes* which occurred in the fishery only during the bloom period was obtained in this gear from July to Sept 2002.

C. ANOVA and DUNCANS TEST

The average catch per unit of *Euthynnus* sp was comparatively high in the bloom month of September when compared to the pre-bloom and post-bloom months. The catch of *Euthynnus* sp per unit of OBDN between the bloom and the non-bloom months were significantly different ($P<0.05$). The catch rate of *Scomberomorus commerson* however did not show significant variation between the bloom and the non-bloom period. The average catch during the months of study along with the results of the level of significance is given in Table. 3.4.

The catch rate of *Euthynnus* sp in outboard drift net between the bloom and the non-bloom period in Bloom II were also significantly different (Table 3.4). The level of variance was significant ($P<0.05$) for the species. The average catch rate was 38.05 kg in the bloom period and 0.17kg in the post-bloom months.

4. OUTBOARD RING SIENE (OBRS)

A.VARIATION IN TOTAL LANDINGS

The OBRS operates at an average distance ranging between 6 to 50 km from the shore and at a depth between 18 to 50 m. The landings from OBRS increased from 792 t in July to 3584 t in the pre-bloom month of August and 3938 t during the bloom period and to 3961 t in October 2002. The increased landings were mainly contributed by sardine landings which is the main targeted species of the gear. The landings of sardine during the period fluctuated between 644 t in July 2002 to 4009 t in November 2002. During the second year, the landings decreased from 3697 t in July 03 to 1745 t in the pre-bloom month of August 2003 and increased slightly to 2507 t during the bloom month in September. In October 2003 the landings were very high, almost 8.5 times more than the catch during the previous month. The catch data of the major groups landed in the gear is represented graphically in Fig. 3.6.

B. VARIATION IN RESOURCES

The fishes *Trichiurus* sp, *Sphyraena* sp and *Epinephelus* spp were obtained in this gear during the bloom period. *Trichiurus* sp was present in the landings of this gear in both Bloom I and II. A heavy landing of 547 t of *Sphyraena* sp was obtained in the pre-bloom month of August 2002 which decreased to negligible amounts by December 02 and was absent in any of the other months. *Epinephelus* sp also showed a similar trend which increased from 8.26t in July to 92.7 t in August 2002 and decreased to 33 t in September and was absent in any other months. *Belone* sp was another finfish resource which was landed (3.3 t) by this gear only in Bloom I.

C. ANOVA and DMRT TESTS

The variation in catch rate of sardines obtained in the outboard ring seine were analysed. The average catch of sardine per unit was highest (2703 kg) in the bloom month of September. There was no significant difference in the average catch rate between the bloom and the non-bloom period ($P<0.05$). The average catch during the months of observation along with the results of the level of significance of the Analysis of Variance are given in Table. 3.5.

5. OUTBOARD GILL NET

A.VARIATION IN TOTAL LANDINGS

The OBGN operates at a distance ranging between 1 to 30 km from the shoreline and at a depth between 2 to 50 m. During Bloom I, the catch increased to 68 t. It decreased slightly to 64 t in the post-bloom month of October. The increased landing in this period was mainly due to the catch of 24.82 t of *Rastrelliger* and 14.2 t of *Scomberoides*. In the following year also 250 t was landed in September 03, while only 53 t were landed in August and it decreased to 114 t in October. The total catch of pelagic, demersal, crustacean and cephalopod resources landed in the gear is represented graphically in Fig. 3.7.

B. VARIATION IN RESOURCES

The increased landing in Bloom I was due to the catch of *Trichiurus* sp which was obtained in this gear only during the bloom period in September and October in both the years. There was a heavy landing of *Trichiurus* sp, 75.3 t in September 2003, which decreased to 40 t in October 2003. Other species which contributed to the increased landings in September 2003 was *Sphyraena* sp with 32.62 t, *Hemirhamphus* sp at 34.8 t and *Caranx* sp at 51 t. *Belone* sp, a finfish was detected only in the bloom period in Oct 02 and from Oct to Nov 2003. *Istiophorus* was another species which was present only in the pre-bloom month of August 2003.

Table. 3.4. Average catch per unit of major fish species which showed variations in the landings of Outboard drift net during the bloom in September 02 and 03 and the results of ANOVA. *

Species	F value	P	Average catch per unit (kg)			
OUTBOARD DRIFT NET-SEPTEMBER- 2002						
			Prebloom	Bloom	Post bloom	Post bloom
			May, July, August	September	October	Nov
Euthynnus sp	8.054	0.005	12.37^{a}	188.67^{b}	1^{a}	0.75^{a}
Scomberomorus sp	0.499	0.771	23.8^{a}	12.92^{a}	26.65^{a}	24.85^{a}
OUTBOARD DRIFT NET-SEPTEMBER- 2003						
			Bloom	Post bloom		
			Aug, Sept	October, Nov, Dec		
Euthynnus sp	23.69	0.017	38.05^{a}	0.17^{b}		

Table. 3.5. Average catch per unit of major fish species which showed variations in the landings of Outboard ring seine during the bloom in September 03 and results of ANOVA. *

Species	F value	P	Average catch per unit					
			Prebloom	Prebloom	Bloom	Bloom	Post bloom	Post bloom
			May	July	August	September	October	November
Sardinella longiceps	1.51	0.198	830.28^{a}	737.2^{a}	740.39^{a}	2703.1^{a}	1487.4^{a}	1324^{a}

*Results of DMRT are shown as superscripts
Nonidentical superscripts(row wise) indicate months with significant differences($P<0.05$).

6. COUNTRYCRAFT GILL NET

A.VARIATION IN TOTAL LANDINGS

The landings from non mechanized gill net was low in the bloom period in both the years when compared to the pre and post-bloom months

In Bloom I it was 5.6 t, which was low when compared to 16.5 t in the pre and 10.85 t in the post-bloom month. In Bloom II the landings were 1.7 t which was low when compared to 6.4 t in the pre and 5.3 t in the post-bloom period. The catch data of the major groups landed in the gear is represented graphically in Fig .3.8.

B. VARIATION IN RESOURCES

Sardinella sp was absent in the catch in September 02 but was present in pre and post-bloom months. *Himantura* sp a benthic ray was obtained in the catch in August and September 02 with landing of 3.92 and 0.31 t respectively. *Arius* sp was landed starting from September and landed upto December 2002.

7. MULTIDAY TRAWL NET

A.VARIATION IN TOTAL LANDINGS

The fishing ground of multiday trawl net operations are farther away from the shore. It operates at a distance ranging from 10 to 110 km from the shoreline and at a depth between 10 to 90 m. The MDTN landings in September 2002 was 1240 t which was slightly lesser than 1324 t in May and increased to 1924 t in October 2002. In the second year MDTN landings were mainly in the night and there was no landing data for the period. The landings in the pre and post-bloom period were low with 386 t in August and 256 t in October 2003. The landing data of the major groups landed in the gear is represented graphically in Fig .3.9.

3.3.2. EFFECT ON COMMNUNITY STRUCTURE

A. AVERAGE TAXONOMIC DISTINCTNESS (Δ^+)

Average taxonomic distinctness showed a reduction during the bloom and the post-bloom period in both the years. The number of genera which contributed to the fishery landings and the average taxonomic distinctness between the monthly species assemblage during the period from October 01 to December 03, is given in Table.3.6. The average taxonomic distinctness (Δ^+) value decreased from 73.7 in May 02 to 65.04 in July 02. It increased slightly to 68.6 in the pre-bloom month of August 02 and decreased to 61.09 in the bloom month of September 02 and further to 58.19 in October 02 after which it increased to 67.03. Even if the taxonomic distinctness was lower in the bloom period, the number of genera was not less which indicated a clear shift in the community structure of the region. The number of genera was 38 in August and September and 40 in October.

The TD value decreased during the Bloom II also. It decreased from 71 in July to 69.8 in August and to 62.37 during the bloom in September and to the lowest of 54.14 in the post-bloom month of October 03. The species numbers was higher in the bloom period than in the months just preceding the bloom but was lower than the months succeeding it. The variation in species numbers and taxonomic distance during the period from October 01 to December 03 is represented graphically in fig.3.10.

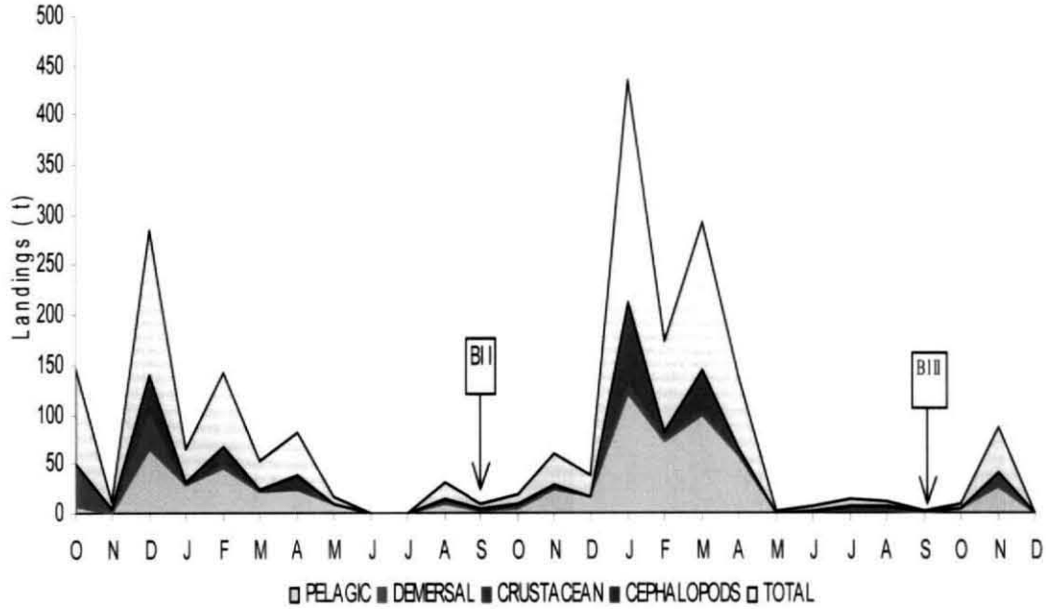


Fig. 3.8 Groupwise landings of nonmechanised gill net at Calicut region from Oct 01 to Dec 2003

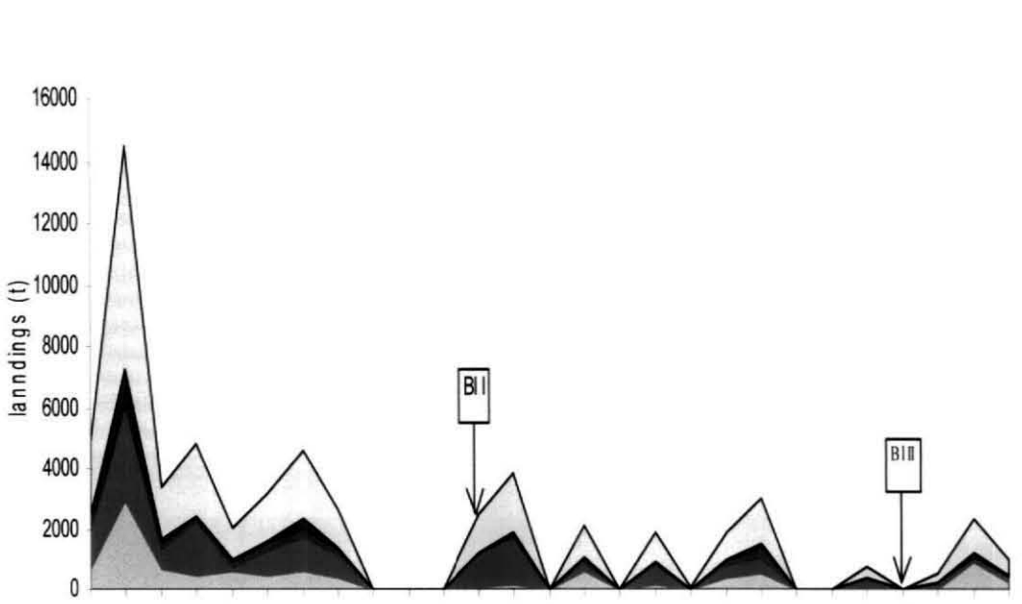


Fig. 3.9 Groupwise landings of multiday trawl net at Calicut region from Oct 01 to Dec 2003

Table. 3.6. Species number and Average taxonomic distinctness for the period from October 01 to December 03.

Month	Number of species	Average Tax.dist
Oct01	28	68.18
Nov01	33	62.47
Dec01	21	68.78
Jan02	33	71.83
Feb02	29	68.58
Mar02	29	74.67
Apr02	35	64.32
May02	33	73.70
Jul02	28	65.04
Aug02	38	68.66
Sep02	38	61.09
Oct02	40	58.19
Nov02	39	67.03

Month	Number of species	Average Tax.dist
Dec02	40	59.84
Jan03	45	67.79
Feb03	35	72.48
Mar03	31	72.63
Apr03	34	69.37
May03	33	67.29
Jun03	17	67.12
Jul03	19	71.01
Aug03	26	69.80
Sep03	24	62.37
Oct03	25	54.14
Nov03	35	62.81
Dec03	38	67.02

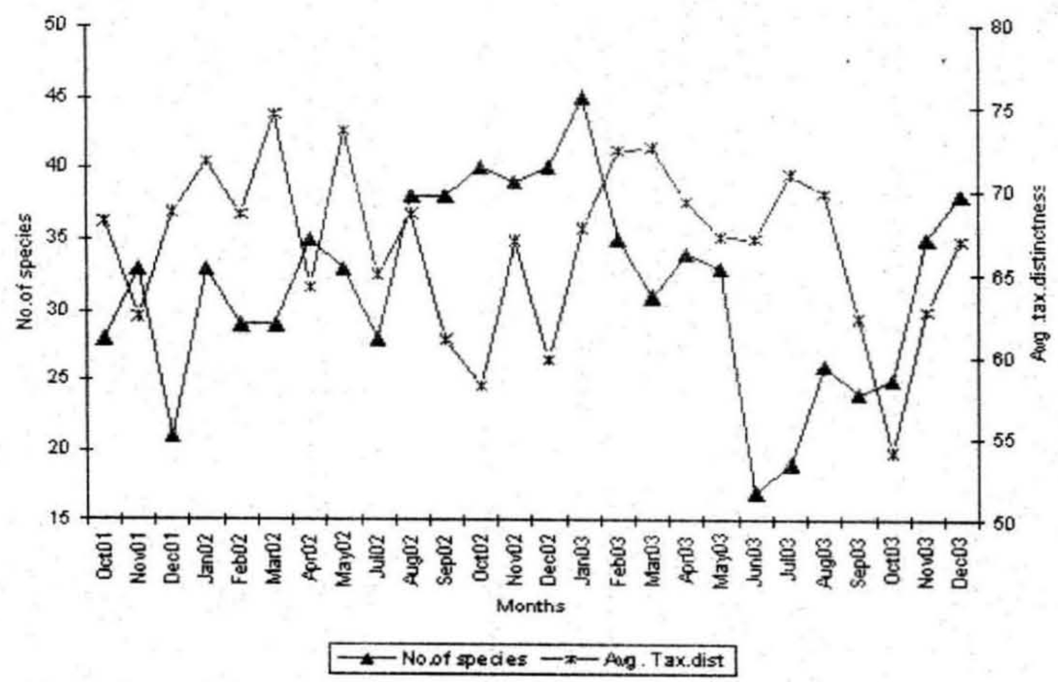


Fig. 3.10 Variation in species numbers and taxonomic distance at Calicut during the period from October 01 to December 03

B.EXPECTED DISTINCTNESS TESTS-FUNNEL PLOTS

Funnel plots were plotted to measure the deviation in taxonomic distinctness during the bloom period from the theoretical mean for the region. The average taxonomic distinctness and significant percentages are given in Table. 3.7.

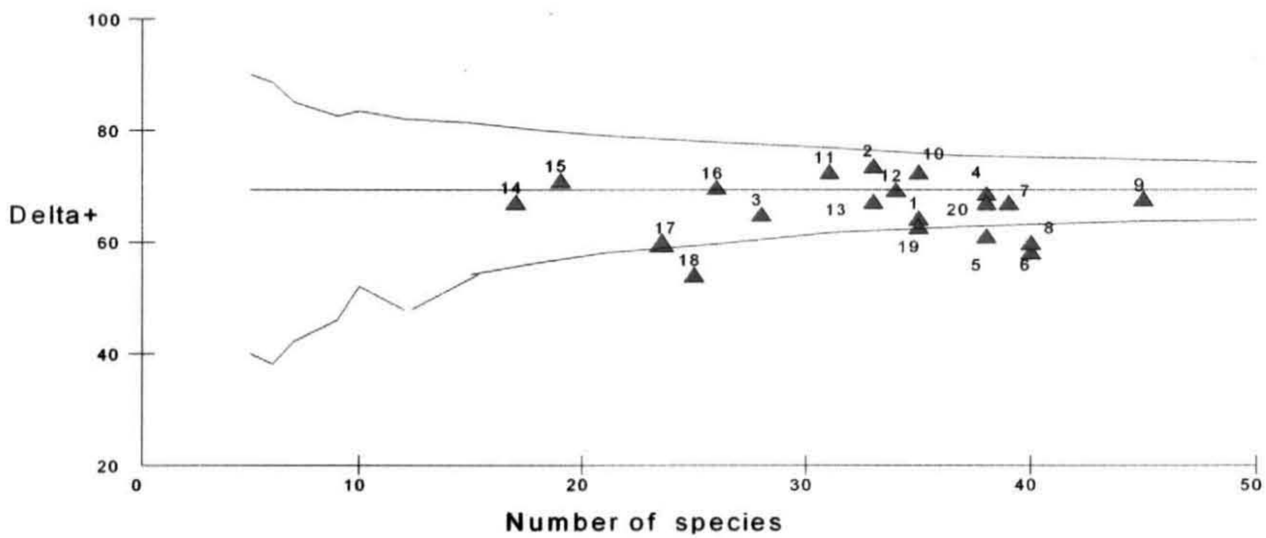
TD showed significant variations in the bloom month of September 02 and more in the post-bloom month of October 02. It also deflected significantly from the theoretical mean in December 02. During Bloom II also the taxonomic distinctness deflected significantly away from the theoretical mean again in the bloom month of September 03 and in the post-bloom months of October and November, with highly significant deflection in October 03.

The funnel plot (Fig. 3.11) compares the average taxonomic distinctness during the months from April 02 to December 03. In the funnel plots it can be clearly seen that the bloom months of September 02 deflected away significantly from the theoretical mean than September03. The post-bloom month of October was also found to deflect significantly away from the theoretical mean in both the instance.

Table.3.7. Average taxonomic distinctness and level of significant variation from the theoretical mean during the period from April to December 03.

Month	Sig %	Month	Sig %
Apr02	18.3	Mar03	46.2
May02	22.3	Apr03	89.2
Jul02	35.9	May03	63.7
Aug02	71.7	Jun03	62.9
Sep02	2.4	Jul03	76.5
Oct02	1.6	Aug03	92.4
Nov02	39.8	Sep03	6.1
Dec02	0.8	Oct03	0.8
Jan03	60.6	Nov03	5.6
Feb03	44.6	Dec03	51

Fig. 3.11. Funnel plot which plots the 95 % confidence intervals for a range of subsamples and the comparison of the average taxonomic distinctness of the samples with the theoretical mean of the region



Central straight line –Theoretical mean; curved line-95% confidence limits

▲ Bloom months

Apr02	1	Oct02	6	Mar03	11	Aug03	16
May02	2	Nov02	7	Apr03	12	Sep03	17
Jul02	3	Dec02	8	May03	13	Oct03	18
Aug02	4	Jan03	9	Jun03	14	Nov03	19
Sep02	5	Feb03	10	Jul03	15	Dec03	20

3.4. DISCUSSION

It is a well-known fact that a good phytoplankton biomass leads to a rich zooplankton crop and high survival of young fish, especially the larvae and the juveniles (Russel, 1936, Harvey, 1950). The fluctuation in the phytoplankton crop of the region in relation to environmental factors therefore reflects in a fluctuation in the recruitment and survival of edible fish stock of a region. An analysis of the fish landings of the Calicut region indicated that the coastal fishery of the region is affected by the *Chattonella marina* bloom, but for a short period.

Fish mortality along the Indian coast has been associated with the blooming of the phytoplankton *Noctiluca, Trichodesmium* and *Gymnodinium mikimotoi.* The avoidance of the bloom area by fishes along the Calicut coast has been reported as early as 1948 by Bhimachar and George. It was observed by these workers that the commercially important shoaling species like sardine and mackerel shift from foul water areas to more favourable grounds in the neighbourhood. This shifting of the fishery has been observed by them during the excessive production of *Noctiluca*, euglenoids, *Nitzschia* and *Oscillatoria* in these waters. The euglenoid was later identified as *C. marina* by Subrahmanyan (1954), who also found a similar avoidance of the bloom region of this alga by the fishes. It was observed by Prabhu *et al.* (1971) that the oil sardine and mackerel which were landed in good quantities during the months preceding a bloom of *Trichodesmium* spp declined with the bloom and revived with the subsidence of the bloom whereas trawl operations in the areas of dense bloom along Goa coast showed fish catches similar in size and composition as in non-bloom areas (Devassy *et al.*, 1978). A dense bloom of *Trichodesmium erythraeum* was found to severely affect the fisheries of the Minicoy island with the fishes completely avoiding the area and period of bloom (Naghabushanam, 1967). Fall in catches along the Karnataka and Goa coasts during the bloom of *Noctiluca* due to the avoidance of the bloom area by the fishes has also been reported (Devassy and Nair, 1987; Shetty *et al.*, 1988). Massive mortality to the marine benthic fishes along the west coast due to *G. mikimotoi* bloom has been reported by Karunsagar and Karunasagar (1992).

Development in fishing craft and gear especially mechanization and motorization has resulted in a drastic change in the fishing activity of Calicut, which was very seasonal in the earlier times. Even in the past the peak fishing season was the post monsoon season as for other regions along the coast. The presence of a seasonal fishery in the inshore waters of the Calicut coast has been mainly linked to plankton production by Chidambaram and Menon (1945);

George (1953); Subrhamanyan (1959). Besides this, according to Mukundan (1980), temperature and salinity also has a key role in this, with temperature playing a dominant role.

Considering the landings of the region, the catch from all the gears had decreased during the bloom period in both the years. Bloom I was a prolonged one and resulted in large scale mortality of finfishes and shellfishes. The fishes which were mostly affected included the demersal fishes eels, groupers, sciaenids and croakers. Fishes are reported to be killed by anoxia during exposure to *C. marina* red tides (Matsusato and Kobayashi, 1974; Ishimatsu *et al.*, 1990). Recently neurotoxins have been isolated from these organisms (Onoue and Nozawa, 1989) and the authors reported that the neurotoxin fraction is more toxic to fishes than the hemolytic and hemoagglutinating fractions but was found to have no effect on their consumers. The toxin analysis at CIFT was positive only for the water samples and not in any of the fish and faunal samples from the region indicating that the toxins does not accumulate and cause any negative effects on man. Bloom I had resulted in the cancellation of all inshore fishing operations in the bloom area for almost three weeks with a severe negative impact on the fishing economy of the region. The mechanized trawl net operations were cancelled completely. There was an absence of fish shoals starting from the pre-bloom and extending upto the post-bloom periods. The alga has a benthic cyst in its life cycle and its germination during the pre-bloom month could have altered the water quality as evidenced by the low dissolved oxygen values, high total suspended solids and toxin production which were unfavourable to the fishes and several marine fauna. The presence of toxin in the water which was produced by the alga must have also caused the avoidance of the region by fish shoals.

More obvious than the decrease in landings was a change in the community structure with a dominance of the community by fishes belonging to higher trophic levels. This was more obvious from the analysis of Av TD tests. Though the species numbers did not vary between the bloom and the non-bloom period, the taxonomic distinctness decreased indicating a stress and a change in the community structure which resulted from the bloom. Warwick and Clarke (1998) who examined 14 species list from a range of impacted and undisturbed UK areas found that the Av TD clearly varied in the impacted areas whereas comparatively pristine locations had Av TD similar to the master species list. An impact study of beam trawling in taxonomic structure of demersal fish assemblages in the North sea, English channel and Irish sea was done by Rogers *et al.* (1999) who observed the Av TD to be clearly reduced in some areas due to the stress caused by trawling.

The landings of all fishes which belonged to lower trophic levels showed a decrease in catch during the blooming of *C.marina* in September 2002. There was however an increase in the catch of sardines mainly from ring seines maybe because of the favourable diatom blooms, especially that of *Coscinodiscus asteromphalus* which occurred preceding the harmful algal bloom. An unusually high landings of sardines were also obtained in October 2003 and this again coincided with a bloom of the same diatom in the region. There was however a decrease in sardine landings from gears like hand and mechanized trawl nets which generally operate very close to the shore. This might be because these fishes must have avoided the bloom region due to some irritant property of this alga and since these gears could not venture in these far off regions for fishing due to their restricted mobility, there was a decrease in the catch rate of these fishes in these gears. The decrease in landings in the gears which operated very near to the shore and the unusual catches of some fishes like sardines in outboard drift net and that of *Epinephelus* sp in outboard ring seines clearly indicates that there was a avoidance of the bloom areas by fishes. Species which were mainly zooplankton feeders were entirely absent which included *Stolephorus* spp, *Thryssa* and *Leiognathus*. Their absence can be attributed either to the absence of their food from the region or to the presence of toxins which might have been transferred through the food web. The planktonic herbivores are able to accumulate algal toxins as well as retain them to a certain degree (White, 1981). This in turn would have resulted in the decrease in catch of the groups which in mainly fed on these zooplankton feeders. This included *Caranx* and *Johnius* spp.

But there was an increase in catch of the predatory fishes mainly *Euthynnus, Trichiurus, Carcharhinus, Saurida, Scoliodon, Scomberomorus,* and *Sepia* spp all of them which occupies the topmost trophic level (Vivekanandan *et al.*, 2003). These species were present in high levels during the pre or post monsoon period during the bloom in Bloom I. Except *Sepia* and *Scoliodon* all the other species were present during Bloom II also. The catch of the sharks *Carcharhinus* and *Scoliodon* which form only a very low percentage of the fishery of the region had also increased to the highest during the bloom period, that of the former in both the blooms and the latter during the first bloom only. They feed mainly on pelagic and shoaling teleosts like sardine, scad, mackerel, squids etc. The catch of these predatory fishes had increased during the first bloom. The catch of sardine was high during the bloom periods but the catch of their predators was high only during the first bloom which indicated that in the first instance they might be in a lethargic condition and so was in a condition in which it could be easily caught due to the algal toxin. Onoue and Nozawa (1989) reported that the neurotoxins of *C. marina* were more toxic than other cytotoxins produced by this species. Exposure of fish to *C. marina* red tide water has been found to result in asphyxiation and erratic swimming behaviour in fishes (Endo *et al.*, 1992).

Cell density also seems to play a major role in deciding the presence of this predator species. In September 02 when there was a long lasting bloom in the region with cell densities reaching as high as 28×10^{7} cells/ l, the presence of the predatory species was maximum in the pre or post-bloom month, probably a period when the toxin levels induced lethargic conditions. With increase in cell density and surface accumulation of the bloom, total avoidance of the bloom area by these fishes was observed. In the second year the densities were however low and the bloom lasted only for a short period of two days only. Hence the catch of these species were high in the bloom month of September itself.

Besides these, some predatory fishes occurred only during the bloom period, either in the pre, post or during the bloom period. Their presence during this period alone indicates the highly sensitive nature of these fishes to the bloom. The demersal fishes *Arius* and *Muraenosox* occurred in the fishery in the bloom period with peak catches in the bloom month. Besides these fishes, the clupeid *Albula vulpes,* a coral fish and the sail fish *Istiophorus* were detected in the pre-bloom months, the former during the first instance of the bloom and the latter during both the blooms. *Arius* sp though occurred in the catch from July to September in the first instance of the bloom, was present in the second instance only in the bloom month. *Arius* spp exhibits shoaling behaviour and vertical and horizontal migration especially during their adult / breeding/ spawning phases of life history. After spawning the brooding males segregate into shoals and move along the surface and prefer shallow waters (Menon, 2003). But the presence of the species only in the bloom month during the second bloom in September 03 and also the peak catch of *Arius* in the first instance in the bloom month of September when there was poor fishing due to bloom suggest that the species is sensitive to the alga. A similar observation was made during the bloom of the alga in Narakkal. The species appeared in large numbers very close to the shore and could be easily caught as they appeared in large numbers at the surface in an asphyxiated condition.

The other demersal fishes which were present during the bloom event in both the years was the eel *Muraenesox*, and the resources which occurred only during the bloom in the first year included the demersal fishes *Priacanthus* and *Pristipomoides* spp and the ray *Himantura* spp. All the species shared the common feature that they were exclusively benthic in habit and also they were all carnivores. Their presence in the catch only during the bloom period therefore indicates a disturbance in their habitat. This suggests the presence of some disturbance to their benthic habitat either due to the toxin produced by the algae or due to the low dissolved oxygen content of these waters. *Istiophorus* which is mainly an offshore resource sometimes comes inshore either due to the lower temperatures of the coastal waters or in search of food (Balan, 1976). Like other predatory species which appeared in this period during the pre-bloom period the presence of abundant food also must have attracted it to the inshore regions.

The catch of all shrimps had decreased during the bloom period. The food of the prawn consists of considerable quantities of phytoplankton elements particularly *Fragilaria, Coscinodiscus, Pleurosigma, Navicula, Cyclotella etc.* (Menon, 1951) on some of which the prawn feeds when the elements sink to the bottom while others feed at the bottom. A similar decrease in shrimp fishery has been reported during the bloom of the dinoflagellate *Gyrodinium aureolem* which revived after the dinoflagellates dispersed (Tangen, 1977).

The effect of *Chattonella marina* on the commercial fishery species and marine fauna of the HAB region is summarized in Table. 3.8.

The fishery of the region as seen from this study seems to be affected by the *C. marina* bloom. But the effect of the bloom is temporary for a short period and immediately increasing after the subsidence of the bloom. According to Gosselin *et al.*, (1989) the kills of adult fishes are sporadic events with limited impacts on fisheries. The emergence of fish larvae and post larvae at a time when the planktonic food web is contaminated by algal toxin could lead to a significant reduction of early survival and threaten recruitment to local stocks. Hence the effect of the algal toxins on the different trophic levels has to be studied in detail.

Table. 3.8. Effect of *Chattonella marina* on the commercial fishery species and marine fauna of the HAB region

Species	**Behaviour/ Reaction to *Chattonella marina***	**Effect on fishery**	**Possible reasons**	**Remarks**
Sardinella sp, *Rastrelliger* sp	Avoidance	Increase in gears operating away from the shore	Stressed environment, exclusion of favourable phytoplankton food	Sensitive
Tunas (*Euthynnus* sp, *Sarda orientalis, Auxis thazard)* Sharks (*Carcharhinus melanopterus, Scoliodon* sp) *Scomberomorus* sp, *Sphyraena* sp, *Istiophorus* sp, *Trichiurus* sp, *Chirocentrus* sp *Sepia* sp	No direct effect	Increase in CPUE	Increased availability of prey	Aggregation/ migration to near shore non-bloom areas
Epinephelus sp, *Himantura* sp *Cynoglossus* sp	Large scale mortality	Appearance in non targeted gears	Avoidance of the bloom area due to the stressed environ.	-
Fishes: *Stolephorus* sp, *Caranx* sp, *Thryssa* sp, *Leiognathus* sp, *Megalaspis cordyla* **Crustaceans:** *M. dobsoni*, *P. indicus*, *Portunus pelagicus*, *P. sanguinolentis*, *Parapenaeopsis stylifera, P. monodon.*	Decreased presence in the region	Decrease in CPUE	Low phytoplankton and zooplankton biomass	Sensitive
Opisthopterus sp, *Esculosa* sp, *Dussumieria* sp, *Anodontostoma* sp, *Chorinemus*, *Lactarius*, *Coryphaena* sp, *Decapterus* sp, *Pristipomoides* sp, *Pellona ditchela*, *Hemirhamphus*, *Rachycentron canadus*, *Otolithes* sp, *Therapon, Ambassis* sp, *Sillago, Strongylura*, *Scatophagus* sp, *Polynemus* sp *Gerres* sp, Formioniger sp, P. argenteus, *Johniops*, *Lutjanus* sp, *Mene maculata*	No visible effect observed	No quantifiable change in fishery observed.	Mostly pelagic, capable of moving away from stressed environ.	Sensitive
Albula vulpes, *Echeneis*	Occurred only during the bloom period	-	Disturbance in the habitat, toxins, low diss.oxygen levels	Highly sensitive
Arius sp	Disorientation/ Erratic swimming behaviour	Increase in CPUE	Disturbance in the habitat, toxins, low diss. oxygen evels	Highly sensitive
Muraenesox sp	Asphyxiation, large scale mortality	-	"	Highly sensitive
Intertidal bivalves: *Perna viridis*, *Mactra* sp, *Donax* sp **Intertidal crustaceans**: *Emerita* sp	Large scale mortality	Fishery temporarily closed	Sedentary nature and continued exposure to HAB	Sensitive

SUMMARY

1. 61 species of marine phytoplankton belonging to 32 genera were recorded from Chombala in north Kerala during the period from October 2001 to September 2002 (first year) and 76 species of 33 genera during the period from October 2002 to September 2003 (second year). From Vizhinjam, along south Kerala, 91species of 30 genera and 90 species of 35 genera were recorded in the sea in the first and second years respectively whereas in the adjacent bay 88 and 95 species belonging to 28 genera were recorded.
2. Diatoms and dinoflagellates, the two most diverse phytoplankton groups were rich in species diversity and density at both the sites, with the diatom species contributing the maximum to phytoplankton community structure. Blue green algae, mainly *Trichodesmium sp* was recorded from Chombala (12.5%) and Vizhinjam bay (8.3%) but was more frequent (25%) from Vizhinjam sea. A rapidophyte *Chattonella marina* was recorded only from Chombala. Diatoms formed 83.5 % of the community at Chombala, while at Vizhinjam they formed 70.9%, the reduction in contribution mainly due to the dominance of dinoflagellates; the diversity being controlled by the two genera *Ceratium* and *Peridinium*.
3. The annual average phytoplankton diversity index at Chombala was 1.88, of which the diversity of diatom and dinoflagellate were 1.81 and 0.29 respectively.
4. The diatom community at Chombala consisted of 10 families, of which members of the families Coscinodiscaceae (32.7%), Fragilaroideae (19.3%) and Biddulphiae (16.4%) were dominant. Among the 7 families of dinoflagellates recorded at Chombala, Gymnodinaceae (24.3%), Peridinaceae (13.3%) and Ceratiaceae (13%) dominated the phytoplankton community structure.
5. The annual average phytoplankton diversity at Vizhinjam bay and sea were 2.13 and 2.09 respectively, of which the diversity indices of diatom and dinoflagellate in the sea were 1.85 and 1.15 and in the bay 1.5 and 0.98 respectively.
6. The diatom community at Vizhinjam sea consisted of 9 families of which members of Chaetocerae (28.4%), Fragilaroideae (19%), Biddulphiae (16.8%) and Coscinodiscacea (16.6%) were dominant. Among dinoflagellates, the families Dinophysiaceae (26.3%), Ceratiaceae (23.7%), Peridinaceae (36.1%) dominated the phytoplankton community structure. At Vizhinjam bay, of the 9 families, members of Chaetocerae (21.6%), Fragilaroideae(21.2%), Biddulphiae (17.3%) and Coscinodiscaceae (16.3%) were dominant and among dinoflagellates, the families Peridinaceae (37.1%), Dinophysiaceae (35.4%), Ceratiaceae (17.9%), dominated the phytoplankton community structure.
7. In the family Dinophysiaceae, the family in which DSP toxicity is shown by most of its members, two species were common *Prorocentum micans* was present in 6 and *Dinophysis caudata* in 15 out of the 24 sampled months at Vizhinjam.

8. The phytoplankton density at Chombala ranged between 2148 cells l^{-1} and $13.5x10^6$ cells l^{-1} and was mainly dependent on diatom density except in September when *Chattonella marina* formed 84 to 99% of the community. At Vizhinjam, the phytoplankton density ranged between 836 to 89,06,800 cells l^{-1} and besides diatoms, the density in the warmer months of the year were also contributed by dinoflagellates (upto 30 %).
9. Cluster analysis for the temporal variation of the phytoplankton community, grouped the months in which centric, pennate and dinoflagellates were dominant into separate clusters. The bloom months and the months with unique species also formed a separate group.
10. Species evenness and diversity values were comparatively low during bloom events and the lowest recorded values were 0.25 and 0.34 during the two major bloom periods of the harmful alga *Chattonella marina*.
11. Of the abiotic factors studied, temperature and salinity along with the major nutrients nitrate and phosphate were found to influence the phytoplankton community structure. An instantaneous increase in phosphate triggered the blooming of phytoplankton in most instances and a positive correlation of phytoplankton density with phosphate (Chombala, r-0.65; Vizhinjam sea, r-0.68; bay, r-0.75) was obtained.
12. Twelve species with known records of toxicity- *Noctiluca scintillans, Gymnodinium mikimotoi, Prorocentrum lima, Prorocentrum micans, Dinophysis caudata, Dinophysis acuminata, Dinophysis miles, Pseudo-nitzschia* sp, *Pseudo-nitzschia pungens, Chattonella marina, Ceratium fusus and Trichodesmium* sp were identified to occur along the Kerala coast. Of these *Prorocentrum lima* and *Chattonella marina* were unique to Chombala and *Ceratium fusus* and *Dinophysis miles* to Vizhinjam.
13. *Pseudo- nitzscia* spp a major causative agent in Amnesic Shellfish Poisoning (ASP) was also noted at both the sites. Mouse bioassay showed the presence of a water soluble toxin in the month in which the species was present in the community.
14. Seventeen algal blooms were recorded along the Kerala coast during the study period. At Chombala there were 9 algal blooms of which 7 were diatom blooms. Two of them were caused by the species *Coscinodiscus asteromphalus* (53,000 and 4,10,000 cells l^{-1}), and one each by *C.janischii* (35,000 cells l^{-1}), *Thalassiothrix frauenfeldii* (88,500 cells l^{-1}), *Thalassionema nitzchioides* (3,75,600 cells l^{-1}) and *Pleurosigma normanii* (26,40,000 cells l^{-1}) and 2 due to the harmful alga *Chattonella marina* ($17 x10^4$ and $13.5x10^6$ cells l^{-1}).
15. In the coastal waters of Vizhinjam, 7 blooms were recorded, of which 6 were diatom blooms. Three of which were caused by *Chaetoceros curvisetus* ($1x10^5$ –$1.82x10^7$ cells l^{-1}) and one each by C. *eibinii* (82 to $85x10^5$ cells l^{-1}), *Fragilaria oceanica* (46,000 and 498000 cells l^{-1}) and *Coscinodiscus sublineatus* (82,850 and 128500 cells l^{-1}) and one harmful bloom caused by the dinoflagellate *Noctiluca scintillans* (102000 and 55000 cells l^{-1}). The harmful dinoflagellate *D.*

caudata formed 23 % of the phytoplankton community at Vizhinjam in December 2001, but no casualties were reported.

16. A massive bloom of *Chattonella marina* with high density of 4.68 x 10 ^{5} cells l^{-1} was recorded for the first time from Narakkal region along Vypin island, central Kerala.

17. Bloom of *Noctiluca scitillans* (98,000 cells l^{-1}) and associated mortality, especially of bivalves was recorded at Thankassery bay, a semienclosed man made bay along south Kerala in October 2002 .

20. 18. At both the stations, it was noticed that the dominant members of the phytoplankton community of the region, the diatoms, bloomed first utilizing the favourable conditions. The diatom *Coscinodiscus asteromphalus* blooms at lower temperatures, <31^{0}C and salinity, <33 ppt. Rather than a definite range, the bloom was found to be stimulated by a sudden lowering of both the parameters associated with rainfall. Cell densities were highest when the temperatures was the lowest, 27^0 C. Nitrate and phosphate were higher, with dissolved inorganic phosphate between 0.4 to 3 μmol l^{-1} and dissolved inorganic nitrate between 2.8 and 23.02 μmol l^{-1}. Associated with the bloom, an increase in TSS levels (10.4- 50.2 mg l^{-1}) and a decrease in dissolved oxygen levels (3.26- 4.83 mg l^{-1}) were observed.

24. Pennate diatoms *Thalassiothrix frauenfeldii, Asterionella japonoica, Thalassionema nitzschoides, Pleurosigma normanii* were found to bloom at lower temperatures (<30^{0}C) but at higher salinities (30 to 36 ppt) and had an absolute requirement for phosphate (>1.25 μmol l^{-1}) as indicated by the triggering of the bloom when there was an addition of phosphate to the system. An increase in nitrogen source was not found essential. *Fragilaria oceanica* bloomed when phosphate was higher than. 2.5 and nitrate between 10.16 to 19 μmol l^{-1} respectively.

25. *Chaetoceros,* the most frequent bloomer at Vizhinjam was found to prefer lower temperatures (27-28°C) but higher salinities (34-35 ppt). Had a lower requirement for nutrients but bloomed whenever there was a slight increase in nutrients, in either nitrate or phosphate. At Vizhinjam the species bloomed when the dissolved inorganic nitrogen was between 0.06 to 11.68 μmol l^{-1} and dissolved inorganic phosphate between 0 to 1.41 μmol l^{-1}.

26. Decrease in surface temperature, increase in surface salinity and an increase in nutrients especially that of phosphate following monsoon and upwelling led to the blooming of *Chaetoceros curvisetus*. A lesser temperature led to the replacement of this species and blooming of another, *C.eibinii*. A further increase in nutrient concentration was followed by the bloom of the diatom *Fragilaria oceanica* succeeded by *Coscinodiscus* and then when the nutrient levels were low, *C. curvisetus* bloomed.

27. *Noctiluca scintillans* was recorded at Chombala, Vizhinjam and Thankassery bay. It was present in low densities at Chombala (100 to 142 cells l^{-1}) but reached bloom densities at Vizhinjam and Thankassery bay (1,02,000 and 98,000 cells l^{-1}). Abundance of diatoms, its main food and stable

weather with high temperatures led to its bloom. At Vizhinjam and Thankassery, the species bloomed when the concentration of nitrate was high>15 μmol l^{-1}.

28. Along the Calicut coast, the bloom of *Chattonella marina* was observed in the transition period between SW and NE monsoon indicating a well-defined periodicity and annual rhythm in appearance. The annual cycle of occurrence of the alga is controlled by the formation of cyst and its germination.
29. The excystement of cysts showed a strong correlation with temperatures and the vegetative cells remained in bloom condition as long as a higher temperature was maintained, perishing with the lowering of temperature associated with the onset of NE monsoon.
30. The phytoplankton blooms in the study sites were found to have two definite pattern, a restricted seasonal occurrence as exemplified by marine diatoms that dominate spring blooms and a non seasonal increase in densities of dinoflagellates in response to short term events such as sunny calm weather that establishes thin upper layer within which motile species accumulate. *Noctiluca* blooms always followed diatom maxima and stable weather. *Chattonella marina* illustrated a different seasonal pattern similar to that of dinoflagellates but the bloom occurs by the excystment of cysts which is triggered by an increase in water temperature and is known to be genetically controlled.
31. Mass mortality of fishes was observed in the region between Puthiyappa and Kappad during the bloom of *Chattonella marina* in September 2002. Major fishes which were killed include *Epinephelus spp, Otolithes sp, Cynoglossus sp* and *Johnius.* Subsequent to this, mass mortality of green mussels of the region was also observed. Besides fishes and mussels, the mole crab *Emerita spp* and the bivalve *Mactra violacea* also suffered severe mortality.
32. Low dissolved oxygen (0.22 mg/l), low pH (7.05) and the production of a lipid soluble toxin were the major reasons for the large scale mortality during the *Chattonella marina* blooms.
33. Extensive mortality ranging upto 100 % of farmed shrimps, especially *Penaues indicus, P. monodon, Metapenaues dobsoni* and *M. affinis* were observed at the tide fed and earthern ponds in the coastal villages of Vypin island due to the bloom *Chattonella marina* in September 2003. Low water circulation and high temperature were found to prolong the growth phase of the alga in the shrimp ponds.
34. Pearl oysters, *Pinctada fucata* and the green mussel *Perna viridis* suspended from the off bottom raft farm of CMFRI in Thankassery bay, in the Kollam district of Kerala were severely affected by the bloom of *Noctiluca scintillans* . A mortality rate of 27% was recorded for adult oysters between the size range of 48-60 mm. The toxin analysis at CIFT did not show the presence of any PSP/DSP toxin in the water and bivalve samples.
35. Though higher densities of *Noctiluca* were observed in Vizhinjam sea (1.02×10^5 cells l^{-1}) than at Thankassery bay (98000 cells l^{-1}), mortality of bivalves was noted only in Thankassery bay

indicating low water circulation and accumulation of chemicals were detrimental to sedentary fauna.. The ammonia was also high in the bay (14.9 $\mu mol\ l^{-1}$) during the bloom period.

36. Fishery was found to be affected during the blooming of *C. marina* along the Calicut coast. Reduction in catch from all the gears was observed.
37. During the prolonged bloom of *C. marina* along the Calicut coast, a shift in the community structure with a dominance of fishes belonging to higher trophic levels was observed. Species which were mainly zooplankton feeders were entirely absent and these included *Stolephorus spp, Thryssa* and *Leiognathus* which in turn resulted in the reduction in catch of the groups which mainly fed on these zooplankton feeders such as *Caranx spp* and *Johnius spp.*
38. A significant change in fishery was an increase in catch of the predatory fishes mainly, *Euthynus, Trichurus, Carcharinus, Saurida, Scoliodon, Scomberomorus,* and *Sepia spp* which occupies the topmost trophic level.
39. The catch per unit per day for *Cynoglossus, Johnius, Thryssa* and *P.stylifera* in the outboard trawl net showed significant variation ($P<0.05$), whereas *M.dobsoni, Penaues indicus* did not show any significant variation ($P>0.05$). The landing of *Euthynnus sps* in outboard drift net was high during the bloom period from that of the nonbloom period and the variation in CPUE was significant ($P<0.05$).
40. Demersal fishes *Arius, Muraenosox, Priacanthus, Pristipomoides spp* and the ray *Himantura spp* occurred in the fishery only during the bloom period.
41. The clupeid *Albula vulpes* and the sailfish *Istiophorus* occurred in the period prior to the bloom, the former during the first instance of *Chattonella marina* bloom and the latter during both the blooms.
42. Taxonomic diversity studies indicated a change in the community structure of commercial finfishes, crustaceans and mollusks due to the bloom of *C.marina*. Though the species numbers did not vary between the bloom and the non bloom period, the taxonomic distinctness differed indicating a change in the community structure.
43. Funnel plots indicated the deviation in taxonomic distinctness during the bloom period from the theoretical mean for the region. Significant variations were observed in the bloom month of September 02 and more in the post bloom month of October 02.
44. The effect of the bloom on the fishery appeared to be temporary reviving soon after the subsidence of the bloom. However the economic losses were high in the year in which the bloom was prolonged since the fishermen abstained from fishing due to the absence of fish shoals and low fish abundance.

RECOMMENDATIONS

The study entitled 'Studies on the incidence of algal blooms along the Kerala coast, India' has brought out several ecological factors which need to be addressed for sustainable coastal development and disaster management measures related to toxins. Though the frequency of occurrences of algal blooms and related causalities are not as severe as in other nations, the study has found that aquaculture practices currently followed can be improved and large scale disasters can be prevented with better management practices. The following recommendations are made based on the results of the research work.

Coastal dinoflagellate monitoring programme: The continuous presence of the DSP causing dinoflagellate *Dinophysis* sp at Vizhinjam has to be treated with caution. As the symptoms of DSP are very similar to that of gastroenteritis it is possible that their presence in many cases goes unnoticed. As the same species shows variation in toxicity in different strains it is important to find out if the species present in this region is a toxic strain. The species was found to have a peak occurrence during the warmer period between the late post-monsoon months to the pre-monsoon months and intense sampling during this period can be recommended to formulate disaster management problems at the earliest.

Endogenic species specific toxin mapping: It is very difficult to identify *Pseudo-nitzschia* upto species level by light microscopy alone. Also, the same species has shown variations in toxicity with locations and seasons. It is therefore essential to identify it upto the species level by specific techiniques like epifluroscence microscopy and specific DNA probes. Clonal cultures of both *Dinophysis* sp and *Pseudo-nitzschia* sp has to be developed from these locations and their endogenic toxin levels analysed.

Aquaculture Management measures: Early warnings when exceptional bloom forming species or toxins reach critical concentration is the most widely used management strategy at present. At a long time scale it would be necessary to assess the risk for harmful events when planning the use of coastal areas. With signs of an imminent bloom, cages and off bottom grow out structures can be relocated/ stocks transplanted away from the region so as to avoid economic losses. This is mainly applicable to farming of *Perna viridis* (mussel), *Crassostrea madrasensis* (oyster) and pearl oyster culture.

Since the bloom of *Chattonella marina* is controlled to a large extent by water temperature, monitoring of water temperatures just before the excystment period is useful in predicting the appearance of the vegetative population in the early stage of the red tide. Also the intake of water into the coastal extensive and semi extensive types of shrimp and fish farms can be stopped once the harmful species is detected in the adjacent sea. Since the maintenance of the cells in the bloom state is to a large extent controlled by water temperatures, methods like increased aeration will lead to disrupt the bloom population and thus reduce the aquaculture losses.

- **Critical criteria for selection of aquaculture sites**: Judicious selection of aquaculture sites based on past or predicted occurrence of HAB's can reduce huge losses. Variables like water temperature, salinity, water stratification profiles and concurrently collected phytoplankton data will help in characterizing sites best suitable for aquaculture. Adverse effects of HABs may be reduced by selecting sites with strong vertical mixing and tidal current velocity. Dinoflagellate and microflagellate blooms are less likely to remain in such areas and turbulence may reduce cell growth rates. Sites with increased nutrient loads and enclosed regions with lesser flushing rates can also be avoided.

- **Effluent discharge management** : Since blooms have been found to be strongly influenced by the amount of nitrates and phosphates, the input of these nutrients from anthropogenic sources has to be strictly controlled. For nutrient sensitive areas improvement of the environment by reduction of these nutrients in the effluents released by municipalities and industries has to be ensured. In Vizhinjam, a slight increase in the amount of these nutrients especially phosphates was found to trigger algal blooms. Thus any further increase in the amount of nutrients to the region will result in a negative impact. The recent occurrence of harmful algal bloom caused by *Gonyalaux digenesis* and *Cochlodinium* spp has been attributed to the discharge of untreated effluents from certain industrial units in the region. Thus effluent treatment guidelines have to be implemented.

- **Satellite based bloom watch and alert system**: For large scale bloom monitoring, many countries use satellites (NOAA coastal watch programme in US) or real time data transmitting ocean buoys (MARINET in Norway) which provide the ability to track discrete water masses that contain HAB's. In India, data from the recently launched OCEANSAT, which gives information on the initiation of the bloom by monitoring sea surface temperatures and chlorophyll measurements can be used to get prior information on the appearance of blooms which will help in charting out appropriate management measures.

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Appendix I-

Results of the analysis of water and faunal samples for the presence of algal toxins at CIFT

YEAR 2001					
Sample	**Date /Month**	**Location**	**PSP**	**DSP**	**Phytoplankton**
Water	28-Oct	Vizhinjam Bay	Absent	Dyspnea,abnormal gait, death in24 hours.	*Dinophysis caudata.*
Water	28-Oct	Vizhinjam sea	Absent	Absent	
Water	29-Oct	Thalassery	Absent	Absent	
Water	11-Nov	Vizhinjam sea	Absent	Absent	
Water	13-Nov	Thalassery	Absent	Absent	
Perna viridis	11-Dec	Thalassery	Absent	Absent	
Water	11-Dec	Thalassery	Absent	Absent	
Paphia *sp*	17-Dec	Dalavapuram	Absent	Absent	
Perna viridis	17-Dec	Dalavapuram	Absent	Absent	
Perna viridis	20-Dec	Pallikandy	Absent	Absent	
Perna viridis	20-Dec	Tikkodi	Absent	Absent	
Perna viridis	28-Dec	Moodadi	Absent	Absent	
Perna indica	30-Dec	Vizhinjam	Absent	Absent	
Water	30-Dec	Vizhinjam Bay	Absent	Absent	
Water	30-Dec	Vizhinjam sea	Absent	Absent	
YEAR 2002					
Sample	**Date/ Month**	**Location**	**PSP**	**DSP**	
Perna viridis	14-Jan	Thalassery	Absent	Absent	
Water	14-Jan	Thalassery	Absent	Absent	
Perna viridis	18-Jan	Moodadi	Absent	Absent	
Perna viridis	18-Jan	Tikkodi	Absent	Absent	
Perna viridis	19-Jan	Pallikandy	Absent	Absent	
Perna viridis	24-Jan	Thankassery	Absent	Absent	
Perna viridis	28-Jan	Vizhinjam	Absent	Absent	
Water	28-Jan	Vizhinjam	Absent	Absent	
Perna viridis	8-Feb	Moodadi	Absent	Absent	
Perna viridis	8-Feb	Tikkodi	Absent	Absent	
Perna viridis	11-Feb	Thalassery	Absent	Absent	
Water	11-Feb	Thalassery	Absent	Absent	
Perna viridis	12-Feb	Vizhinjam	Absent	Absent	
Water	12-Feb	Vizhinjam	Absent	Absent	
Perna viridis	11-Mar	Thalassery	Absent	Absent	
Water	11-Mar	Thalassery	Absent	Absent	
Water	12-Mar	Vizhinjam sea	Absent	Absent	
Water	7-Apr	Vizhinjam 1	Absent	Paralysis,Diarrhoea, Dyspnea ,Death in 10 minutes.	*Pseudo- nitzschia pungens, Trichodesmium sp*
Water	7-Apr	Vizhinjam 2	Absent	Moved restlessly, imbs stretched .	*Trichodesmium* sp, *Dinophysis miles*
Perna viridis	13-Apr	Thalassery	Absent	Absent	
Water	13-Apr	Thalassery	Absent	Paralysis,Diarrhoea, Dyspnea, Death in 8 minutes.	*Pseudo- nitzschia pungens, Prorocentrum micans*
Perna viridis	13-May	Thalassery	Absent	Absent	
Water	28-May	Vizhinjam 1	Absent	Absent	
Water	28-May	Vizhinjam 2	Absent	Absent	
Perna indica	10-Jun	Thalassery	Absent	Absent	

Sample	Date /Month	Location	PSP	DSP	Phytoplankton
Water	10-Jun	Thalassery	Absent	Absent	
Perna indica	10 June	Vizhinjam	Absent	Absent	
Water	10 June	Vizhinjam sea	Absent	Absent	
Water	15-Jul	Thalassery	Absent	Absent	
Water	26-Jul	Vizhinjam Bay	Absent	Absent	
Water	26-Jul	Vizhinjam sea	Absent	Absent	
Perna indica	13-Aug	Thalassery	Absent	Absent	
Water	13-Aug	Thalassery	Absent	Absent	
Water	20-Aug	Vizhinjam Bay	Absent	Absent	
Water	20-Aug	Vizhinjam sea	Absent	Absent	
Perna viridis	3-Sep	Elathur	Absent	Absent	
Water	4-Sep	Puthiyappa	Absent	Died in 5 minute. Presence of water soluble toxin.	*Chattonella marina*
Fish	4-Sep	Puthiyappa	Absent		
Fish	4-Sep	Puthiyappa	Absent		
Fish	4-Sep	Puthiyappa	Absent		
Water	11-Sep	Konad 9.30 AM	Absent	Unconscious, later recovered.	*Chattonella marina*
Water	11-Sep	Konad Bloom 1	Absent	Coma,died 2 hours Presence of water soluble toxin.	*Chattonella marina*
Water	11-Sep	Konad Bloom 2	Absent	Died in 5 minute. Presence of a water soluble toxin.	*Chattonella marina*
Water	11-Sep	Konad11.30 AM	Absent	Dyspnea,paralysis. Death in 5 minutes.	*Chattonella marina*
Water	11-Sep	Konad2.30 AM	Absent	Coma,died in 1/2 hour. Presence of water soluble toxin	*Chattonella marina*
Water	12-Sep	Kappad 11.30AM Bloom	Absent	Died in 10 minute.	*Chattonella marina*
Water	12-Sep	Kappad 11.30AM Control	Absent	Dyspnea,coma, died in 50 minutes.	*Chattonella marina*
Water	12-Sep	Kappad 2.30 PM	Absent	Died in 10 minute.	*Chattonella marina*
Water	12-Sep	Kappad Noon	Absent	Coma ,death.	*Chattonella marina*
Water	13-Sep	Chombal 12PM	Absent	Died in 5 minute.	*Chattonella marina*
Donax sp	13-Sep	Chombala	Absent	Absent	
Perna viridis	13-Sep	Chombala	Absent	Absent	
Water	13-Sep	Chombala 2PM	Absent	Absent	
Water	13-Sep	Chombala 9.30 AM Bloom	Absent	Died in 5 minute.	*Chattonella marina*
Water	13-Sep	Chombala 9.30 AM non bloom	Absent	Absent	
Perna viridis	13-Sep	Elathur	Absent	Absent	
Perna viridis	13-Sep	Moodadi	Absent	Absent	
Perna viridis	13-Sep	Tikkodi	Absent	Absent	
Water	27-Sep	Kappad 1	Absent	Absent	
Perna viridis	27-Sep	Tikkodi	Absent	Absent	
Water	28-Sep	Chombala bloom	Absent	Absent	
Water	28-Sep	Chombala non bloom	Absent	Absent	
Water	28-Sep	Puthiyappa	Absent	Absent	
Perna viridis	28-Sep	Thalassery	Absent	Absent	
Perna viridis	29-Sep	Chombala	Absent	Absent	
Perna viridis	14-Oct	Thalassery	Absent	Absent	
Water	14-Oct	Thalassery	Absent	Absent	

Sample	Date /Month	Location	PSP	DSP	Phytoplankton
Perna indica	12 Nov	Vizhinjam	Absent	Absent	
Water	12 Nov	Vizhinjam Bay	Absent	Absent	
Water	12 Nov	Vizhinjam Sea	Absent	Absent	
Water	29-Nov	Vizhinjam Bay	Absent	Absent	
Water	29-Nov	Vizhinjam Sea	Absent	Absent	
Perna indica	16-Dec	Moodadi	Absent	Absent	
Water	16-Dec	Moodadi	Absent	Absent	
Perna indica	16-Dec	Pallikandy	Absent	Absent	
Water	16-Dec	Pallikandy	Absent	Absent	
Perna indica	16-Dec	Tikkodi	Absent	Absent	
Water	16-Dec	Tikkodi	Absent	Absent	
YEAR 2003					
Perna viridis	4-Jan	Thalassery	Absent	Absent	
Water	4-Jan	Thalassery	Absent	Absent	
Perna viridis	18-Jan	Moodadi	Absent	Absent	
Perna viridis	18-Jan	Tikkodi	Absent	Absent	
Brown Mussel	20-Jan	Vizhinjam	Absent	Absent	
Water	20-Jan	Vizhinjam	Absent	Absent	
Perna viridis	10-Feb	Moodadi	Absent	Absent	
Perna viridis	10-Feb	Tikkodi	Absent	Absent	
Perna viridis	11-Feb	Thalassery	Absent	Absent	
Water	11-Feb	Thalassery	Absent	Absent	
Perna viridis	20-Feb	Vizhinjam	Absent	Absent	
Water	20-Feb	Vizhinjam	Absent	Absent	
Perna viridis	12-Mar	Thalassery	Absent	Absent	
Water	12-Mar	Thalassery	Absent	Absent	
Water	21-Mar	Vizhinjam sea	Absent	Absent	
Water	17-Apr	Vizhinjam 1	Absent	Absent	
Water	17-Apr	Vizhinjam 2	Absent	Absent	
Perna viridis	13-Apr	Thalassery	Absent	Absent	
Water	13-Apr	Thalassery	Absent	Absent	
Perna viridis	3-May	Thalassery	Absent	Absent	
Water	20-May	Vizhinjam 1	Absent	Absent	
Water	20-May	Vizhinjam 2	Absent	Absent	
Perna indica	10-Jun	Thalassery	Absent	Absent	
Water	10-Jun	Thalassery	Absent	Absent	
Perna indica	18 June	Vizhinjam	Absent	Absent	
Water	18 June	Vizhinjam sea	Absent	Absent	
Water	5-Jul	Thalassery	Absent	Absent	
Water	20-Jul	Vizhinjam Bay	Absent	Absent	
Water	20-Jul	Vizhinjam sea	Absent	Absent	
Perna indica	3-Aug	Thalassery	Absent	Absent	
Water	3-Aug	Thalassery	Absent	Absent	
Water	25-Aug	Vizhinjam Bay	Absent	Absent	
Water	25-Aug	Vizhinjam sea	Absent	Absent	
Water	15-Sep	Chombal	Absent	Absent	
Perna indica	15-Sep	Chombala	Absent	Absent	
Water	4 Sept	Narakkal sea	Absent	Died in 10 minute. Presence	*Chattonella marina*
				of water soluble toxin	
Water	4 Sept	Narakkal farm 1	Absent	Died in 10 minute.	*Chattonella marina*

Sample	Date /Month	Location	PSP	DSP	Phytoplankton
Water	4 Sept	Narakkal farm 2	Absent	Died in **15** minute.	*Chattonella marina*
Water	4 Sept	Narakkal farm 3	Absent	Died in 5 minute.	*Chattonella marina*
Fish	4 Sept	Narakkal sea	Absent	Absent	
Fish	4 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	4 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	4 Sept	Narakkal farm 2	Absent	Absent	
Villorita cyprinoides	4 Sept	Narakkal farm 3	Absent	Absent	
Water	6 Sept	Narakkal sea	Absent	Absent	
Water	6 Sept	Narakkal farm 1	Absent	Died in 10 minute.	*Chattonella marina*
Water	6 Sept	Narakkal farm 2	Absent	Died in 10 minute.	*Chattonella marina*
Water	6 Sept	Narakkal farm 3	Absent	Absent	
Fish	6 Sept	Narakkal sea	Absent	Absent	
Fish	6 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	6 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	6 Sept	Narakkal farm 2	Absent	Absent	
Villorita cyprinoides	6 Sept	Narakkal farm 3	Absent	Absent	
Water	9 Sept	Narakkal sea	Absent	Absent	
Water	9 Sept	Narakkal farm 1	Absent	Absent	
Water	9 Sept	Narakkal farm 2	Absent	Absent	
Water	9 Sept	Narakkal farm 3	Absent	Absent	
Fish	9 Sept	Narakkal sea	Absent	Absent	
Fish	9 Sept	Narakkal sea	Absent	Absent	
Villorita cyprinoides	9 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	9 Sept	Narakkal farm 2	Absent	Absent	
Villorita cyprinoides	9 Sept	Narakkal farm 3	Absent	Absent	
Water	11 Sept	Narakkal sea	Absent	Absent	
Water	11 Sept	Narakkal farm 1	Absent	Absent	
Water	11 Sept	Narakkal farm 2	Absent	Absent	
Water	11 Sept	Narakkal farm 3	Absent	Absent	
Fish	11 Sept	Narakkal sea	Absent	Absent	
Fish	11 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	11 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	11 Sept	Narakkal farm 2	Absent	Absent	
Villorita cyprinoides	11 Sept	Narakkal farm 3	Absent	Absent	
Water	23 Sept	Narakkal sea	Absent	Absent	
Water	23 Sept	Narakkal farm 1	Absent	Absent	
Water	23 Sept	Narakkal farm 2	Absent	Absent	
Water	23 Sept	Narakkal farm 3	Absent	Absent	
Fish	23 Sept	Narakkal sea	Absent	Absent	
Fish	23 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	23 Sept	Narakkal farm 1	Absent	Absent	
Villorita cyprinoides	23 Sept	Narakkal farm 2	Absent	Absent	
Villorita cyprinoides	23 Sept	Narakkal farm 3	Absent	Absent	

APPENDIX- II

On Occurrence of Certain Biotoxins along the Kerala Coast

A. SONA, K. ASHOK KUMAR, M.K. MUKUNDAN
R. JUGUNU*, V. KRIPA* and C.P. GOPINATHAN*
Central Institute of Fisheries Technology
P.O. Matsyapuri, Cochin - 682 029, India

Occurrence of algal blooms has been reported from the coastal regions of Kerala. A study was conducted to collect detailed information on location and seasonality of the incidence of PSP and DSP toxins in the bivalves of this region for providing advance warning to avoid shellfish poisoning. A database on the hydrographic parameters in relation to algal blooms and toxic blooms at selected stations, which are sites of frequent blooms in the past years, was prepared. Data on the presence of biotoxins in mussels and water samples periodically collected from Moodadi, Tikkodi, Pallikandy, Elathur, Thalassery, Fort Cochin and Vizhinjam, which are the main mussel landing centers of the state, are reported. Apart from this, the occurrence of PSP and DSP in edible oyster, *Crassostrea madrasensis* from Central Marine Fisheries Research Institute's farm in Ashtamudi lake and the black clam *Villorita cyprinoides* from Vembanad lake, monitored regularly, are also discussed. In August 2000, the bloom of *Gymnodinium pulchellum* in Fort Cochin region was found to contain paralytic shellfish poison. Six other blooms were observed in Calicut, Chombala, Narackal, Vizhinjam, and Thankassery during the period July-September 2001. The causative species were identified as *Noctiluca scintillans*, *Heteroaulacus* spp. and *Prorocentrum micans* all of which were non-toxic. The study revealed that the incidence of PSP producing algal blooms are low along the Kerala coast and level of toxin is well below (<21 $\mu g.100g^{-1}$) the toxic limit of 80 $\mu g.100g^{-1}$ of shellfish meat. In the light of the hydrographic data, the causative algal species and the occurrence of PSP and DSP toxin in the environment and bivalve meat, the safety of molluscan fishes of Kerala coast is discussed.

Key words: **Biotoxins, algal bloom, bivalves, Kerala**

India, being a major exporter of seafood products has to assure the quality and safety of her products. The incidence of marine biotoxins in seafood has become a threat to consumers. The two major biotoxins that cause threat to Human health are paralytic shellfish toxin (PSP) and diarrhetic shellfish toxin (DSP). Paralytic shellfish toxins are a group of neurotoxin produced mainly by dinoflagellates belonging to genus *Alexandrium*, *Pyrodinium*, and *Protogonyaulax*. These dinoflagellates occur both in the tropical and moderate climate zones (Hall, 1982; Krogh, 1988; van Egmond *et al.*, 1993). Shellfish grazing on these algae accumulate the toxins. The maximum permitted level of paralytic shellfish toxin in Bivalve Mollusks is 80 $\mu g.100g^{-1}$edible tissue (Council of the European Communities, 1991).

Kerala state along the west coast of India is the major producer of bivalves. Bivalves especially mussels (*Perna indica* and *Perna virides*) and clams (*Villorita cyprinoides, Paphia malabarica,* and *Meritrix casta*) are fished and marketed locally. Considering the importance of bivalves it is necessary to study the living environment of the bivalves and also the possibility of algal blooms, which may cause toxins in the bivalves. Hence it is necessary to study the existence of toxin producing algal bloom and the amount of toxin, which may be present in the bivalves growing in that environment. The present study has been taken up with this view.

Materials and Methods

Three sampling sites along the Kerala coast namely Thalassery, Fort Cochin and Vizhinjam, which had the incidence of algal blooms in previous years were selected and studied from April 2001 to September 2001. Mussel and water samples, periodically collected from these centers were analysed for PSP.

The hydrographic variation and phytoplankton composition of the coastal waters at Thalasherry, Cochin and Vizhinjam were monitored regularly. The chemical characteristics of the surface water collected were analyzed for dissolved orthophosphate (Murphy & Riley, 1962), nitrate and nitrite (Morris & Riley, 1963) and chlorophyll pigments by Spectrophotometric (Parsons *et al.*, 1984). Dissolved oxygen was measured by Winkler method (1888), and salinity using salinometer (ATAGO – S/Mill-E, Japan). Total suspended solids (TSS), total Organic Carbon (TOC), surfactants (SURF), biological oxygen demand (BOD) and chemical oxygen demand (COD) were measured by Pastel UV Spectrophotometer. Qualitative assessment of the phytoplankton at these sites was done by collecting the plankton and identifying them to the species level (Subramanyan, 1971). The

The green mussel, *Perna viridis* collected from north and central Kerala and brown mussel, *Perna indica* from the natural bed of Vizhinjam were transported to the lab in the live condition and refrigerated. The samples were later analyzed for PSP by mouse assay (AOAC, 1990). The samples were collected monthly and during bloom period samples were collected daily.

Results and Discussion

Algal blooms:

Table 1 shows the date, location and algal species notices during the bloom. The blooms were noted mainly in the post monsoon period. *Noctiluca scintillans, Noctiluca milaris, Heteroaulacus* sp. and *Prorocentrum micans* have all been responsible for harmful algal blooms. *Prorocentrum micans* has been reported to cause toxic bloom in Northern Britany (Lassus & Berthome, 1988) and in Portugal (Pinto & Silva, 1956). However in Kerala the bloom was mild and did not cause any toxic condition. In the regular monthly observations on the phytoplankton composition along north Kerala, toxic algae in substantial quantities were not observed. *Leptocylindrus dandius, Astrionella japonica, Thallassiothrix fraunfeldii, Cosinodiscus* sp., *Rhizosolenia* sp., *Thallassinema nitzchoides* are the major species found in this area.

Table 1. Date, location and algal species identified during algal bloom

Date	Location	Algal species	Intensity
25-07-2001	Calicut	*Noctiluca scintillans*	–
04-08-2001	Chombala	*Noctiluca scintillans*	Golden yellow colored bloom
09-08-2001	Fort Kochi	*Heteroaulacus sps*	Very dense bloom. Sea was brick red colored in the morning, intensities to a dark brown color by afternoon. By next afternoon coloration had disappeared. Fish mortality was reported.
26-08-2001	Vizhinjam	*Noctiluca milaris*	–
17-08-2001	Thankassery	*Prorocentrum micans*	Red patchy discoloration in the harbour area
11-09-2001	Chombala	*Prorocentrum micans*	Red discoloration as narrow streak. Fish mortality reported.

Table 2 shows the seasonal changes in the hydrographic parameters in Fort Kochi region. The bloom of *Heteroaulacus* sp. in Narackal reported of fish mortality. This might be due to clogging of algae to the gills. Along Vizhinjam, *Noctiluca milaris* bloomed in August 2001. However, in this region harmful algae were observed though they did not cause any water discolorations or mortality. The plankton blooms formed by the dinoflagellate *Noctiluca miliaris* have been implicated in mortality (Subramanian, 1985).

The gross productivity, which was 2.13 $mgC.l^{-1}.day^{-1}$ prior to the bloom, increased to 5.97 $mgC.l^{-1}.day^{-1}$ during the bloom and further rose to 10.11 $mgC.l^{-1}.day^{-1}$ after the *Noctiluca scintillans* bloom at Chombala. The total quantity of phytoplankton, namely gross productivity was increased, clearly indicating the algal growth. The net productivity (i.e. Gross productivity – Respiration) shows a slight increase. Similar trend was observed for Chlorophyll a, c and BOD. A recent investigation of remote sensing of harmful algal blooms shows high near-shore chlorophyll a in the bloom region (Yin *et al.*, 1999).

Table 2. Seasonal changes of hydrographic parameters at Fort Kochi

Parameters		April	May	June	Aug.*	Aug.**	Sept.
Productivity	Gross	0.853	1.9395	1.7066	6.542	3.491	1.1308
($mgC.l^{-1}.day^{-1}$)	Net	0.627	0.8467	0.8524	0.9344	0.873	0.9899
Chlorophyll	A	1.248	1.346	1.873	78.01	44.05	–
($\mu g.l^{-1}$)	B	0.645	0.327	1.055	0.00	1.047	–
	C	0.320	0.785	1.629	23.21	26.48	–
Nutrients	NH_3	3.45	0.19	0.00	23.28	6.59	0.00
($\mu g.l^{-1}$)	PO_4	1.59	1.36	0.86	4.71	3.84	0.76
	NO_3	1.17	2.90	0.19	4.19	2.38	0.01
	NO_2	6.90	0.48	0.06	0.26	0.42	0.08
Temperature (°C)		29	28	28.2	28	28	28.3
Salinity (%)		33	34	27	33	33	32
pH		8.02	8.21	8.10	9.0	8.21	8.14
Dissolved oxygen (mg O_2 l^{-1})		4.46	3.24	5.27	5.85	4.07	4.76
Total suspended solids (ppm)		6.46	4.2	6.6	60.5	46.5	12.5
Total organic carbon (ppm)		1.8	1.4	1.6	13.2	7.2	1.6
Surfactants (ppm)		0.4	0.3	0.4	0.4	0.3	0.2
Chemical oxygen demand (ppm)		5.4	4.8	5.3	43	23.6	5.6
Biological oxygen demand (ppm)		2.4	1.4	2.2	15.6	10.6	2.1

* Represents the hydrographic parameters recorded during the bloom of *Heteroaulacus* sp. in Narackal on 9-8-2001;

** Represents the hydrographic parameters recorded during the bloom of *Heteroaulacus* sp. in Narackal on 10-8-2001;

No collection in July since the sea was rough

Table 3. Seasonal changes of hydrographic parameters at Thalassery

Parameters		April	May	June	July	Aug*	Sept**
Productivity	Gross	1.4547	1.4547	2.1337	5.974	10.114	5.67
($mgC.l^{-1}.day^{-1}$)	Net	0.4849	0.9698	1.2802	0.4267	5.2362	3.927
Chlorophyll	A	2.622	5.8036	0.3206	6.0806	10.287	5.741
($\mu g.l^{-1}$)	B	2.58	0.6221	0.0	0.928	0.9662	0.9427
	C	2.4	1.8732	0.0226	0.7658	1.764	2.2871
	NH_3	177.51	1.45	4.19	9.38	9.32	0.34
Nutrients	PO_4	13.39	1.73	1.00	2.37	2.37	2.88
($\mu g.l^{-1}$)	NO_3	0.12	1.27	0.36	2.79	0.26	4.16
	NO_2	3.77	9.37	10.65	11.87	6.97	0.04
Temperature (°C)		31.5	29	27	28	27	29
Salinity (%)		30	34	31	33	35	35
PH		7.4	8.21	8.17	7.78	7.78	8.32
Dissolved oxygen ($mg\ O_2.l^{-1}$)		9.62	5.37	5.722	7.713	7.7128	5.3424
Total suspended solids (ppm)		15.6	2.4	10.1	38.5	38.5	10.2
Total organic carbon (ppm)		13.1	0.9	10.1	38.5	2.2	2.1
Surfactants (ppm)		5.0	0.4	0.3	0.4	0.4	0.4
Chemical oxygen demand (ppm)		35.0	0.3	1.2	7.6	7.6	3.1
Biological oxygen demand (ppm)		13.2	0.4	0.3	3.1	3.1	2.8

* Represents hydrographic parameters recorded during the bloom of *Noctiluca scintillans* in Chombala on 4-8-2001.

** Represents hydrographic parameters recorded during the bloom of *Prorocentrum micans* in Chombala on 11-9-2001.

Table 4. Seasonal changes of hydrographic parameters at Vizhinjam

Parameters		April	May	June	July	August*
Productivity	Gross	1.9395	0.8534	1.1454	1.9382	3.4908
($mgC.l^{-1}.day^{-1}$)	Net	0.9698	0.4267	0.8268	0.9691	1.7454
Chlorophyll	A	0.274	1.9354	0.723	0.856	4.6296
($\mu g.l^{-1}$)	B	1.8808	0.0	0.682	0.483	0.4253
	C	2.944	3.5638	0.939	1.213	1.3663
	NH_3	0.00	0.00	0.00	0.12	3.33
Nutrients	PO_4	0.54	0.73	0.82	0.90	1.82
($\mu g.l^{-1}$)	NO_3	0.10	0.04	9.03	8.43	22.87
	NO_2	1.11	4.73	0.28	0.46	0.76
Temperature (°C)		30	29	27	28.5	29
Salinity (%)		33	34	26	28	35
PH		8.21	7.56	8.02	8.13	8.17
Dissolved oxygen ($mg\ O_2.l^{-1}$)		4.523	3.234	4.32	4.64	4.8336
Total suspended solids (ppm)		2.4	8.0	4.2	6.4	46.6
Total organic carbon (ppm)		0.9	2.5	2.5	0.9	7.2
Surfactants (ppm)		0.4	0.3	0.3	0.4	0.4
Chemical oxygen demand (ppm)		0.4	8.2	0.3	4.3	3.2
Biological oxygen demand (ppm)		0.4	3.7	0.3	2.4	0.5

* Represents the hydrographic parameters recorded during the bloom of *Prorocentrum micans* in Thankassery on 17-8-2001.

Toxicity appears to be related to the high concentration of the algal cells, a water temperature of 70° to 75°F, high pH, and length of exposure to sunlight (Jurgens, 1953; Muncy, 1963). Temperature recorded during bloom was 28-29°C. In Hong Kong, red tides higher incidence of red tides was recorded when the sea temperature was around 20-23°C (Chan & Liu, 1991).

Salinity and pH showed slight increase characteristic of the species. The dissolved oxygen, nutrients have found to be increased. A 10-fold increase in mean dissolved phosphate levels and 5-fold increase in mean dissolved nitrate levels resulted in a very large increase in phytoplankton, and increase in red tide blooms (Chan & Hodgkiss, 1987; Hodgkiss & Chan, 1983; 1986; 1987). TSS and COD values, which were low before the bloom increased at the time of bloom and decreased after the bloom. At Narakkal, similar trend was observed for these parameters and also for Gross productivity, Chlorophyll a, c, phosphate content, TOC and BOD at *Heteroaulacus* sp. bloomsite. Contrary to this, during the bloom of *Prorocentrum micans* at Chombala, the gross and net productivities, nitrite content and BOD showed a decreasing trend from the pre bloom period. This might be due to varied nutrient requirement of different algal species responsible for bloom.

The mussel samples analysed for the presence of paralytic shellfish toxins by mouse bioassay indicated no detectable toxins. However fish kills had been reported in Narackal. This could be due to the clogging of algae to the gills.

Paralytic shellfish poisoning is a worldwide problem. Phytoplankton blooms occur at the eutrophic zones. Prior to blooms, the nutrient levels will rise. The blooms, however, did not cause any danger to humans. More work is to be done in these areas to provide warning to shellfish farmers and consumers about period of incidence of blooms and effect of toxicity.

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